CHAPTER 3:
Hazard Risk in the State of Hawai'i

3.0 Introduction

The hazards examined in this section were originally those defined by the Hawai‘i Statewide Hazard Mitigation Forum. The Forum identified the following natural hazards as most prevalent in Hawai‘i and targeted these hazards for the statewide public awareness campaign: hurricane and strong wind; flooding; drought; wildfire; landslide, erosion; earthquake; tsunami; and, volcanic activity. Although these hazards were identified as being the most critical for the state, these natural hazards have varying degrees of severity on each island. For example, Hawai‘i Island is the only island currently experiencing volcanic activity. Changes and additional knowledge about hazard risks for the state have resulted in expansion of this chapter with additional discussion on identification of threats related to climate change, health-related hazards, and homeland security.

There are a number of different ways to categorize hazards. Many of these hazards occur in tandem with other events or may aggravate conditions that cause other types of disasters. For example, an earthquake may propagate a tsunami, drought conditions may fuel wildlfires, and tropical storms may exacerbate coastal erosion. Climate extremes, such as the El Niño-Southern Oscillation warm event, may contribute to droughts, fires, and erosion, potentially followed by a cold event, or La Niña, where some places may experience severe flooding. For this document the hazards have been divided into the following categories: meteorological and hydrological hazards; seismological and geological hazards; and technological and human-induced hazards.

This document was intended to provide an overview of Hawai‘i State’s natural hazards as well as incorporate research on the hazards, their impacts, and documented damage. Each hazard is covered more thoroughly in the county hazard mitigation plans for Hawai‘i, Kaua‘i, Maui, and the City & County of Honolulu, which describe the particular risks and impacts in local jurisdictions throughout the state. The references in the chapter appendix were reviewed by the Multi-Hazard Science and Technical Advisory Committee of the Statewide Hazard Mitigation Forum to provide a resource list for more comprehensive analysis of natural hazards. Discussion of mitigation actions related to each of these hazards will be conducted in the mitigation chapter of this document.

The following table (Table 3-1) lists the most devastating disasters experienced in the State of Hawai‘i. This chapter provides additional information about the hazards in Hawai‘i and provides the context for active and ongoing hazard mitigation work described in the other chapters of this document.

Table 3-1. Hawai'i's Worst Natural Disasters by Cost and Loss of Life.

Cost $	Event	Lives Lost	Location	Date
2.4 b	Hurricane Iniki	3	Kaua'i, O'ahu	Sept. 11 , 1992
234 m	Hurricane Iwa	1	Kaua'i, O'ahu	Nov. 23, 1982
100 m	Earthquake	0	Hawai'i	Oct. 15, 2006
35 m	Heavy Rain. Flash Flooding	0	East O'ahu	Dec. 11,1987- Jan 02, 1988
27.6 m	High Surf/ Winds. Hvy Rains, Flooding	0	Statewide	Jan. 7- 16, 1980
26.5 m	Tsunami (Chile. S. America)	61	Hilo (Statewide)	May 22, I960
26 m	Tsunami (Aleutian Islands)	159	Hilo (Statewide)	Apr. 1,1946
6 m	Earthquake	0	Hilo	Nov. 16,1983
6 m	Volcanic Eruption	0	Kapoho	Jan. 13, I960
6 m	Heavy Rain, Flooding	0	Hawai'i	Feb. 17-22, 1979
6 m	Heavy Rain, Flooding	0	Hawai'i	Nov. 15-18, 1979
5 m	Hurricane Dot	0	Kaua'i	Aug. 06,1959
5 m	Earthquake	0	Hilo	Apr. 26,1973
5 m	Tsunami	0	Statewide	Mar. 09, 1957

Source: National Weather Service. updated from http://www.insurancejournal.com/magazines/west/2006/11/06/features/74392.htm

The National Weather Service Pacific Regional Headquarters lists the following events that have occurred since 2004 (http://www.prh.noaa.gov/hnl/pages/events.php). These events were significant but only three of these resulted in disaster declarations. The Mānoa Flood and the Extended Wet Period in March 2006 that resulted in a dam break on Kaua'i and extensive flooding on O'ahu, as well as the Kiholo Earthquake. The earthquake occurred near the Island of Hawai'i on October 15, 2006 and resulted in a disaster declaration, but did not result in a tsunami, and was therefore not included in the following list.

- **Tsunami November 15, 2006**: At 1:14 AM HST an 8.3 moment magnitude earthquake struck near the Kuril Islands in the northwest Pacific Ocean prompting the Pacific Tsunami Warning Center to issue a Tsunami Watch for Hawaii. The watch was cancelled around 5 AM when it was determined that a large destructive tsunami had not been generated. PTWC and Civil Defense officials cautioned that even though the tsunami was not large, there would be potential hazards to those in and near the water from strong or unusual currents and sea level fluctuations. The first tsunami waves reached Hawaii around 7:20 AM. Rapid changes in sea level were reported around the state including 60 inches at Kahului, 45 inches at Haleiwa, and 18 inches at Waikiki. Surges of water overran the parking lot at the small boat harbor Nawiliwili Bay on Kauai and reached the highway near Laniakea on Oahu.

- **Heavy Rainfall - Oct 31 to Nov 2, 2006** : Heavy rainfall across much of Hawai'i during the period was the result of two systems. The first being left over moisture from an old front that pooled along the windward sides of the islands. The light easterly wind flow helped push the moisture over windward sections of the islands, resulting in some showers on October 30. By October 31, the destabilized further as an upper level trough of low pressure moved toward Hawaii. The more unstable conditions resulted in locally heavy rainfall that persisted into the afternoon hours of November 1. The excessive rains produced flooding over portions of windward Kauai and Oahu and triggered a significant landslide that closed Oahu's Pali Highway. As the upper level low pushed across the state on November 2, it once again triggered the development of a cluster of thunderstorms near Oahu during the late morning. These thunderstorms brought one last round of flooding to portions of Oahu and then to Molokai and Maui during the afternoon as it slid southeast down the island chain. Such heavy rain events due to the combination of an old front, or shearline, and an upper level low pressure are not uncommon and happen several times a year.

- **Small Tsunami of May 3, 2006**: At 527 am HST, a 7.9 magnitude earthquake occurred south of Tonga. This prompted the Pacific Tsunami Warning Center to issue a Tsunami Watch for Hawaii. As additional data from buoys and tide gauges in the South Pacific arrived at the Pacific Tsunami Center over the next couple of hours, the indication was that no large, potentially damaging tsunami had been created. Thus at 739 am HST, the Tsunami Watch for Hawaii was cancelled. Although the risk for a damaging tsunami no longer existed, a small tsunami had been generated by the quake. The tsunami reached Hawaii around noon HST and was recorded by a number of tide gauges across the state maintained by NOAA's National Ocean Service. Based upon the gauge readings, the tsunami that reached Hawaii was generally one-half to one foot (6 to 12 inches), although local effects in Kahului Harbor resulted in a slight enhancement with the tsunami about 1 1/2 ft high. The only report received at this office was of unusual tidal surge behavior observed at Hanalei Bay, Kauai shortly after 100 pm HST.

- **Unprecedented Extended Wet Period across Hawaiʻi, February 19 to April 2, 2006:** The winter wet season of 2005-2006 started off extremely dry across Hawaii as a strong jet stream persisted across the north Pacific, keeping all significant rain makers well to our north. In early February as the jet stream across the Pacific weakened, likely in concert with a developing weak La Niña pattern, and allowed storm systems to move much farther south. By mid-February, a blocking pattern developed across the entire northern hemisphere, in effect keeping storm systems from moving much. In the Pacific, this pattern took on the form of what is called a "rex-block" with high pressure locked into place south of Alaska and low pressure in a position just west of Hawaii. Normally during March, Hawaii will see several strong trade wind events and shear line passages with considerable rainfall over the windward, or north- and east-facing, slopes of the islands. Instead, March 2006 brought only 5 days of low level winds from a trade direction with the remainder being from the southeast through southwest due to the persistent pattern of low pressure to our west. It was not a single low that persisted for nearly 7 weeks, but rather a series. A particular low would last for a few days and weaken and then give way to a developing new low as a shortwave would drop into the persistent upper level trough and provide additional energy to the system and creating another "Kona Storm". When this occurred, strong southwest winds aloft would extend as far south as 5 degrees north latitude, tap into the deep tropical moisture and transport it over the state. This moisture, combined with the instability in the atmosphere would produce another round of thunderstorms and heavy rains (http://www.prh.noaa.gov/hnl/pages/events/weeksrain/weeksrainsummary.php).

- **Jan 8-9, 2005 Severe Storms on Kauaʻi and Oʻahu**: During the evening and overnight hours of January 8 and 9, a line of powerful thunderstorms moved across Kauai and Oahu producing strong wind gusts, wind damage and a small tornado. In fact, this line was identical to systems that usually affect the Central Plains and eastern parts of the mainland during spring and summer. Although relatively rare for Hawaii, such strong to severe thunderstorms do occur, mainly during the winter, when strong cold fronts and jet stream dynamics are most likely to reach as far south as Hawaii. In this particular case, we had a combination of strong low level winds (40-50 mph) ahead of an approaching cold front providing convergence and strong jet stream winds high aloft (100 mph), providing upper level divergence, in the area.

- **Extreme North Shore Surf - December 15, 2004:** A large low pressure complex developed in the northwest Pacific, off the coast of Russia, beginning late on December 11. Pressure in this storm system fell to 964 millibars (28.47 inches) and produced winds approaching hurricane strength (65 knots or 74 mph) in a small area on the south side of the main low (satellite and pressure analysis). Meanwhile, a large area of 40 to 50 knots (45 to 60 mph) winds blew from the northwest over an area almost 1500 miles in length. Such strong winds over such a large area, called a fetch, produced wave heights over 40 feet. The energy in these waves then moved southeast, away from the strong winds and toward Hawaii, becoming what is referred to as a swell. Since the earth is round, swells appear to move in a curved route when looking at a "flat" map. These routes are referred to as "Great Circles". To determine whether or not a swell will impact Hawaii, we look for wind directions (yellow streamlines in the image) blowing parallel to a great circle path. This was exactly the situation that set up on December 13. As a swell propagates, the energy within it dissipates resulting in progressively smaller swell wave heights. Over the course of the 500 to 800 miles the swell traveled before reaching Hawaii, approximately 50% of the energy was dissipated, meaning the swell had diminished to a little over 20 feet. The swell began reaching Buoy 1 about 200 miles northwest of Kauai during the day on December 14. The swell height peaked at 26 feet just before midnight HST (10 UTC) December 15 and then began to fall (buoy chart). Travel time to the islands from the buoy for such a swell are roughly: 5 hours to Kauai, 8 to Oahu, 11 to Maui and 14 to the Big Island. Thus the highest surf occurred on Kauai before daybreak, around sunrise on Oahu and late morning and afternoon on Maui and the Big Island. The darkness made it impossible to get observations from Kauai. Of course as the swell moved down the island chain, it slowly dissipated. The buoy offshore of Waimea Bay, Oahu reported a peak swell height of about 19 feet.

- **Mānoa Valley Flood October 30, 2004:** During the late afternoon an area of showers being pushed west by the low level tradewind flow interacted with the Koʻolau Mountains on the windward (east) side of Oʻahu. As the air was pushed up over the mountains, the unstable environment allowed those showers to rapidly develop into a thunderstorm and remain focused over a small area of southeast Oʻahu (infrared satellite image). This thunderstorm, locked into place due to the terrain, produced very heavy rainfall totals in just a few hours (radar loop). The focus of the heaviest rain occurred over the southern portion of the Koʻolau Mountains on Oʻahu, resulting in Mānoa Stream overflowing its banks and causing significant flooding in Mānoa Valley, including the University of Hawaiʻi campus (see the website for more detailed information at http://www.prh.noaa.gov/hnl/pages/events/ManoaFlood20041030/).

- **Darby Rainfall Event August 3-4, 2004:** What would eventually become Hurricane Darby developed about 2800 miles east-southeast of Hawaiʻi on July 26, 2004. Moving to the northwest and then west, Darby ultimately reached peak intensity of 105 kt (120 mph) on July 29 (satellite). Shortly thereafter, Darby moved into an area of cooler waters and stronger upper level winds, both are unfavorable for a hurricane to sustain itself. Just two days later, Darby was nothing more than just a low level swirl of clouds and showers with winds of only 20 to 25 knots as it was about 1000 miles east of the state (satellite). This area of moisture was being pushed westward toward Hawaiʻi by the tradewind flow. An upper level low was located just to the northwest of the state, and this had made the atmosphere slightly unstable over Hawaii. As the remnant swirl of Darby moved closer to the unstable region, thunderstorms began to develop. The first round of thunderstorms occurred just north and east of the Big Island on August 2 (satellite). That night, additional showers and thunderstorms formed across parts of the Big Island, particularly the normally dry Kona side (satellite, radar). Rainfall amounts of 2 to 5 inches over a few hours were reported, and this led to flooding and closures of several roads. During the day on August 3, the remnants moved across Maui (satellite, radar). Locally heavy rainfall occurred on the southeast flank of Haleakala, otherwise the development of heavy and widespread rainfall was limited. However that changed during the night as the remnants approached Oahu. Once again thunderstorms developed, affecting the entire island of Oahu and dumping several inches of rain in a few hours (satellite, radar). A few streams overflowed their banks and minor landslides occurred, both resulting in some road closures. The main effect was significant ponding of water on the roads, which impacted the morning rush hour. By mid day August 4, Darby's remnants began to affect Kauai (satellite), but the bulk of the heaviest rainfall stayed south of the island, thus sparing the island from any heavy rains, with the exception at the normally wet Mount Wai‘ale‘ale.

Even though many of the events described above never resulted in disaster declarations, these events caused damage and there were costs associated with tasking additional personnel to monitor these events and issue warnings. There were also costs to a few residents and business owners that received minor damages and had to close operations for a few days to recover. These reported events are all climate anomalies, which may become more frequent with changes in climate.

Technological and human-induced hazards were not the original focus of this mitigation plan; however, they should be mentioned because these hazards can occur simultaneously with any natural hazard, and will exacerbate the impacts. The dam failure in Kaua‘i occurred at the same time as flashflooding and heavy rainfall. As a result, dam inspections and mitigation efforts have been prioritized following the March 2006 event.

The assets and the mitigation chapters review agencies and organizations in place to deal with hazardous materials. Some information on Homeland Security has also been included since any terrorist threat combined with a natural hazard would be more devastating. Planning for any hazard cannot occur in isolation. Detailed plans for all the human-induced hazards have been prepared by agencies with specific oversight. Because of the sensitive nature of this data, specific details have not been made public but are available to those responsible for managing these types of hazards.

3.1 Hurricanes and Strong Winds

3.1.1 Hurricanes and Strong Winds

Hurricanes, tropical storms, and typhoons are collectively known as tropical cyclones. They are among the most devastating, naturally occurring hazards in the United States and its territories. Tropical cyclones are classified as follows:

Hurricane - An intense tropical weather system with a well-defined circulation and maximum sustained winds of 74 mph (64 knots) or higher. In the western Pacific, hurricanes are called "typhoons." Similar storms in the Indian Ocean are called "cyclones."

Tropical Storm - An organized system of strong thunderstorms with a defined circulation and maximum sustained winds of 39 to 73 mph (34-63 knots).

Tropical Depression - An organized system of clouds and thunderstorms with defined circulation and maximum sustained winds of 38 mph (33 knots) or less.

Table 3-2. Saffir-Simpson Hurricane Scale.

Storm Type	Category	Pressure in inches	Winds	Surge	Damage
Tropical Depression	TD	--	less than 39 mph	--	--
Tropical Storm	TS	--	39 to 73 mph	--	--
Hurricane	1	higher than 28.94"	74 to 95 mph	4' to 5'	Minimal
Hurricane	2	28.50" to 28.91"	96 to 110 mph	6' to 8'	Moderate
Hurricane	3	27.91" to 28.47"	111 to 130 mph	9' to 12'	Extensive
Hurricane	4	27.17" to 27.88"	131 to 155 mph	13' to 18'	Extreme
Hurricane	5	lower than 27.17"	greater than 155 mph	higher than 18'	catastrophic

Source: http://www.wwlp.com/wx/hurricane/saffir.html

3.1.2 Hurricane-Related Damage

Storm surge, rain, and wind cause most of the damage associated with hurricanes. Storm surge floods and erodes coastal areas, salinates land and groundwater, contaminates water supply, causes agricultural losses, damages structures and infrastructure, and results in loss of life. Rain damages structures, infrastructure, and agriculture, and results in loss of life. Hawaii's topography channels rain onto mountain slopes, causing flash flooding and landslides. Strong winds can create tremendous amounts of debris (which impact utilities and transportation), cause agricultural losses, destroy lightly constructed buildings with inadequate foundational support, and result in loss of life.

3.1.3 History of Strong Winds in Hawai‘i

Winds often accelerate as they descend from the mountains to the coastal plain. In many instances, the highest recorded gusts associated with passing storms have occurred on the side of the island opposite the storm's approach as winds burst in downdrafts across ridge crests from the steep pali (cliffs) to the coast below.

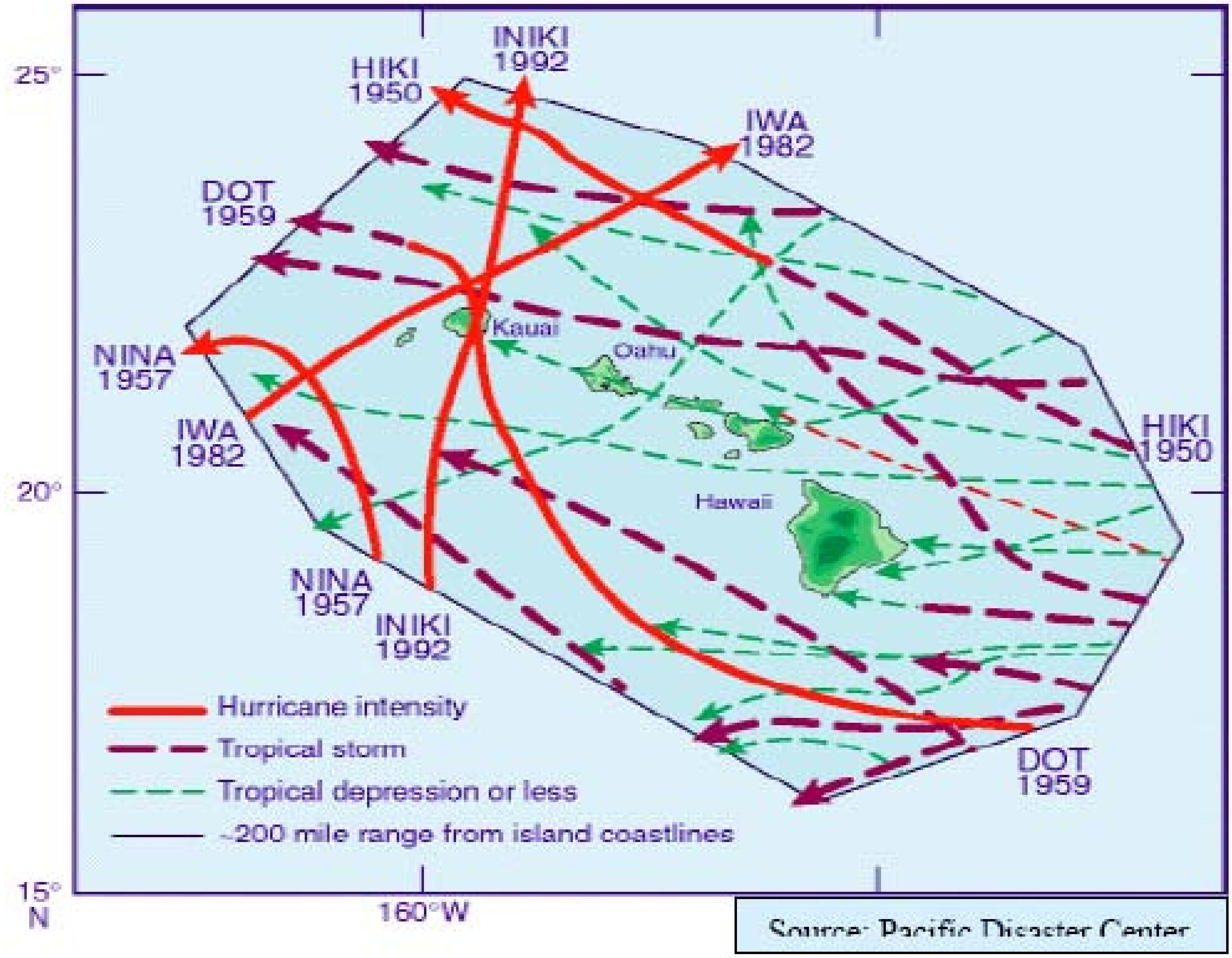
On Kaua‘i, numerous high wind events have affected the entire island, and many were associated with passing storms. Hurricanes Dot (1959), ‘Iwa (1982), and Iniki (1992) were exceptionally damaging. Hurricane Dot packed sustained winds of 75 mph with gusts of 165 mph as it passed directly over Kaua‘i. Winds and flooding led to $5.5-6 million in agricultural losses and hundreds of houses and trees were damaged.

Hurricanes ‘Iwa and Iniki both produced high waves ranging 20-30 feet and winds over 125 mph. Although Hurricane Iwa passed to the northwest of Kauai, the high surf it produced, combined with a 5-6 foot storm surge, flooded 600 feet inland in areas between Kekaha and Po‘ipu and caused $312 million in damage. Ironically, despite the massive flooding and wind damage to the Po‘ipu area, redevelopment following ‘Iwa occurred in precisely the same location, only to be devastated 10 years later by Hurricane Iniki. Today, these same areas are once again densely developed, although decisions were made by some developers to put the golf courses closer to the shoreline and increase the setbacks for building development.

On September 11, 1992, Hurricane Iniki, the strongest and most destructive hurricane to hit the Hawaiian Islands, made landfall just west of Port Allen on Kaua‘i's south shore. Iniki's winds were sustained at 130 mph and gusts topped 160 mph. Winds and waves destroyed 1,421 houses and caused minor to heavy damage to some 13,000 houses. Although Hurricanes ‘Iwa and Iniki did not strike O‘ahu directly, communities on O‘ahu’s Wai‘anae Coast suffered severe damage.

Of course not all of the storms make landfall in Hawai‘i, and actual hurricane strikes in Hawai‘i are relatively rare in modern record (Schroeder 1993). More commonly, near misses that generate large swell and moderately high winds causing varying degrees of damage are the hallmark of hurricanes passing close to the islands.

Figure 3-1. Historical Storm Tracks in the Vicinity of Hawai‘i.



Source: Pacific Disaster Center.

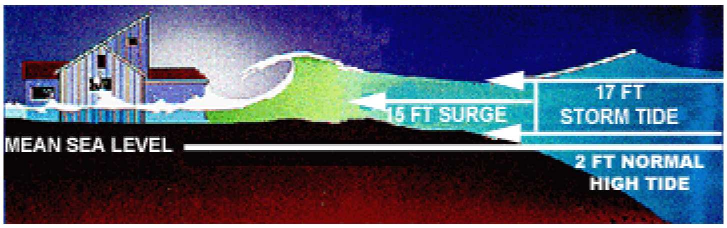
Table 3-3. Significant Hawaiian Hurricanes of the 20th Century.

Name	Date	Damage (1990 Dollars)	Deaths
Mokapu Cyclone	Aug. 19, 1938	Unknown	Unknown
Hiki	Aug. 15, 1950	Unknown	Unknown
Nina	Dec. 2, 1957	$900,000	4
Dot	Aug. 6, 1959	$28,000,000	0
Iwa	Nov. 23, 1982	$394,000,000	1
Iniki	Sept. 11, 1992	$1,800,000,000	4

3.1.4 Hurricane – Storm Surge

About 90% of the deaths that occurr along the coastline and result from hurricanes are caused not by wind, but by storm surge. Storm surge flooding is water that is pushed up onto otherwise dry land by onshore winds. Friction between the water and the moving air creates drag that, depending upon the distance of water (fetch) and velocity of the wind, can pile water up to depths greater than 20 feet (6.1 m) from the shoreline inland. The storm surge is the most dangerous part of a hurricane as pounding waves create very hazardous flood currents. Worst-case scenarios occur when the storm surge occurs concurrently with high tide. For example, if a normal astronomical tide is 2 feet and a storm surge is 15 feet, then the resulting storm tide will be 17 feet in height:

Figure 3-2. Storm Surge.



Source: National Oceanic and Atmospheric Administration (NOAA), National Hurricane Center.

As a hurricane nears land, the surge of water, topped by battering waves, can move ashore along an area of the coastline as much as 100 miles wide. Stream flooding is much worse inland during the storm surge because of backwater effects.

Unfortunately, low atmospheric pressure, tidal stage, coastal topography, and location relative to the eye of the hurricane make hurricane-induced storm surge difficult to predict before a hurricane impacts a location. Thus, overwash mitigation must be enacted prior to the event.

3.1.5 Potential Losses from Future Hurricanes

In addition to placing more property in harm's way, coastal population growth has created life-threatening problems associated with storm warnings and evacuation. It is becoming more and more difficult to ensure that ever-rising numbers of residents and summer visitors can be evacuated and transported to adequate shelters during storm events. In some locations, hurricane evacuation decisions must be made long before hurricane warnings can be issued. Further, a significant percentage of the coastal population has not experienced a hurricane and may be less likely to prepare and respond properly before, during and after such an event. Even the best organized governmental response may be unable to meet the large demand for emergency shelter, food and water in many heavily populated areas.

If a Category 1 storm as strong as Hurricane Iwa, with winds gusting at 74 mph, strikes any of the islands in the state, we can guess from past experience that about 12% of the houses and apartments could be destroyed or heavily damaged and about 18% would probably experience minor damages.

If a Category 3 storm strikes any island with the same force as Iniki, with winds raging at 130 mph, we can guess that about 38% of the homes will be heavily damaged or destroyed. An additional 40% will probably have minor damages. The following information was extrapolated from Kauai Damage in 1982 and 1992.

Table 3-4. Estimated Cost of Storms in Hawaii ($ billion in 1992).

	Oahu	Maui	Hawaii	Kauai
Iwa-Strength Storm	$4.5-7.5	$0.8-1.4	$0.8-1.4	$0.3-0.6
Iniki-Strength Storm	$13.9-23.3	$2.7-4.5	$2.6-4.4	$1.1-1.9

Source: Hawaii Coastal Hazard Mitigation Planning Project, Office of Planning, December 1993.

3.1.6 Asset Damage

The modeling of the potential hurricane damage rests on assumptions that the overall damage pattern resemble those on Kaua‘i after ‘Iwa and Iniki, and that the estimates of damage from Iniki and ‘Iwa are applicable. From these and other data, primarily from the current State Data Book, estimates of asset damage and economic impact have been generated.

While it is impossible to calculate precisely how a hurricane might affect a specific area due to the difference in storm characteristics and variability in topological and structural features, the estimates are still useful. They give a sense of the order of magnitude of the potential destruction and allow for the preliminary evaluation of effectiveness of policy recommendations.
A brief description of how the estimates were calculated follows. The asset damage estimates are presented first, followed by the estimates of economic impacts.

3.1.7 Residential Property

The American Red Cross surveyed the damage to residential units shortly after both storms. The “street sheets” rated every house on every street with damage on a scale of 0 = no damage: 1 = minor damage; 2 = major damage; and 3 = destroyed. The results were tabulated, and the category counts formed part of the basis for the FEMA reports and action. The island wide percentage of damage to the stock of residential units by storm and classification is:

Table 3-5 Damage Percentage to Residential Units by Storm and Classification

	Iniki	Iwa
Destroyed	8%	3%
Major damage	30%	9%
Minor damage	41%	18%
Total	**79%**	**30%**

In both storms about 10% of residential units suffering damage were destroyed. In Iniki a higher proportion suffered major damage (37% to 30%), while a smaller proportion suffered minor damage (51% to 60%).

3.1.8 Clean- up Costs

The final item is the clean-up cost. After Iniki the clean up cost was an estimated $48 million, or 3.2% of the asset damage estimate. These numbers were then adjusted by the inflation rate for 2002. The estimated clean- up cost and total damage estimates are:

Table 3-6. Iniki: Clean Up Costs and Total Damage ($ millions)

	Subtotal	Clean- Up	Total
Honolulu	18, 805	573	24,330
Maui	3,489	110	4,693
Hawaii	3,413	108	4,591
Kauai	1,516	48	2,039

Table 3-7. ʻIwa: Clean Up Costs and Total Damage ($ millions)

	Subtotal	Clean- Up	Total
Honolulu	5,849	185	7,857 m
Maui	1,100	35	1,480 m
Hawaii	1,087	34	1,462 m
Kauai	477	15	642 m

3.1.9 Economic Impacts and Construction Repair

It is assumed that most of the structural damage (residential, accommodation and other business) will require mostly skilled construction labor for repairs. To determine the labor needs for the repair work, the current construction value per worker is needed. The ratio is the 1991 General excise tax base for contracting ($4334 million) divided by the 1991 statewide job count in the contact construction industry (33,500) or $129,373. The structural damage totals are divided by the construction value per worker to calculate the number of workers needed and then multiplied by the average annual wage ($37, 791) to calculate the estimated total wages, assuming the number of workers were employed for a year. It would then need to be updated by the inflation index (1.304).

It is important to remember that there is an opportunity cost to the work and income generated from the structural repairs of hurricane damage. The workers replacing structures are not building new ones. No new income is generated unless previously employed workers are now employed in the repair work, or unless workers are accruing "overtime" to meet the higher demand.

3.1.10 Wind Modeling and Mapping Efforts

New wind mapping efforts are being funded by the Pre-Disaster Mitigation Program and State of Hawaii Hazard Mitigation Forum. These efforts are being conducted in review of the new 2003 International Building Code (IBC) that has been approved for the City and County of Honolulu. In conjunction with this effort, the City and County of Honolulu is in the process of creating new orthoimagery, as well as a 3D GIS spatial database to be used for the purposes of Real Property taxation, but could also be used for other efforts involving hazard mitigation.

3.2 Flood Hazards

Floods are a temporary inundation of land from excessive rainfall or wave action. Flood problems exist where development has encroached into floodplains, which are areas that receive flooding. The distinction between a flood and "flash-flood" is usually determined by the amount of warning (less than six hours for a flash-flood) that affected areas might receive prior to the flood conditions.

Flash floods may trigger hazardous events such as mud and landslides, structural bridge failures, and other threatening conditions. Rainfall intensity and duration are the primary source of flash floods. Intensity is the rate of rainfall, and duration is how long the rain lasts. Other factors include topography, soil conditions, and ground cover. **Dam Failure** causes another type of flash flood. The sudden release of the impounded water can occur during a flood that overtops or damages a dam or it can occur on a clear day if the dam has other defects which could lead to failure.

Floods are a long-term event and may last several days, or even weeks. Hurricanes and earthquakes directly cause flood conditions such as "storm surge" or tsunami respectively. There are also floods that have characteristics associated with the geographic areas they are in, such as river, coastal and urban flooding.

Riverine Floods in Hawaii are usually triggered by hurricane or tropical storm rains.

Coastal Floods are caused by winds generated from tropical storms and hurricanes or intense offshore low-pressure systems that can drive ocean water inland and cause significant flooding.

Urban Floods are triggered because the paved streets cannot absorb the rainfall. Therefore, the streets become a river and people can lose their property and sometimes their lives.

With unprecedented events and climate anomalies causing unprecedented flooding events, it has been difficult to predict the impacts of these events. The Mānoa Flood, which occurred on October 30, 2004 resulted in a disaster when the stream moved off course after exceeding the capacity at a bridge crossing. The challenge to mitigating the hazard due to stream flooding is in large part one of obtaining adequate warning in the case of flash floods and in improving plans for development in areas of known historical flooding.

3.2.1 Flood Advisories

The National Weather Services uses specific words when they issue alerts to the public about dangerous flood-related conditions.

Flash flood watch: A flash flood is possible in the area. Stay alert.

Flash flood warning: A flash flood is imminent or occurring; take immediate action.

Urban and small stream advisory: Flooding of small streams, streets, urban storm drains, and low-lying areas.

From February 19 through April 2, 2006 alone, the National Weather Service Forecast Office in Honolulu issued over 500 non-routine products providing important information to people in Hawaii about imminent or ongoing severe weather (Nash, Rydell, and Kodama 2006, May 11, http://www.prh.noaa.gov/hnl/pages/events/weeksrain/weeksrainsummary.php). These products included:

- **111 Flash Flood Warnings** *(means flooding is likely to occur within the next hour or already occurring)*. Flash Flood Warnings were issued on 26 days through the period. Typically there are 2 to 3 flash flood events each year during this same time period across the state. Our average lead time before flooding actually began was over 70 minutes.
- **88 Special Marine Warnings** *(for waterspouts and/or strong thunderstorms over the water within 40 miles of land that are capable of producing winds greater than 40 mph or large hail).* Normally we issue about 30 special marine warnings in a year.
- **11 Severe Thunderstorm Warnings** *(means severe thunderstorms will likely occur within the next 30-60 minutes*). Normally we have 2 to 4 severe thunderstorm events statewide each year.
- **5 Winter Weather Advisories** *(means snowfall of 2 to 5 inches is likely in the next 24 hours)*
- **3 Severe Thunderstorm Watches** *(means severe thunderstorms with winds above 58 mph and/or large hail are possible within 6 hours)* on Feb 19, March 24, March 30. Normally the office issues 1 to 2 watches a year.
- **2 Winter Storm Watches** (*means snowfall of 6 inches or more is possible in the next 36 hours).*
- **2 High Wind Warnings** *(means sustained winds above 40 mph and/or gusts above 60 mph)* for the upper summits of Mauna Kea and Mauna Loa. Strong winds are a fairly common event on the summits, especially during the winter.
- **1 Winter Storm Warning** *(means snowfall of 6 inches or more is likely in the next 24 hours).*
- **1 Tornado Warning** (means a tornado is likely within the next 30 minutes). Normally there are 1 or 2 tornadoes each year somewhere in Hawaii.
- **Flash Flood Watches** (means flooding *possible* within the next 36 hours) were in effect for the following periods of time:
  - February 19-2
  - March 1-3
  - March 8-11
  - March 13-19
  - March 21- April 2

3.2.2 Flood Risk in the State of Hawaiʻi

Kauaʻi County

Stream flooding on Kauaʻi is characterized by numerous flash floods as well as prolonged flooding associated with slowly passing rainstorms that saturate the soils. Kauaʻi, famous as one of the wettest places on Earth, receives between 20 and 80 inches of annual rainfall along the coast and more than 400 inches at the higher elevations of Mt. Waiʻaleʻale.

Flash floods resulting from a storm on December 14, 1991 that dropped over 20 inches of rain in 12 hours over Anahola, caused five deaths, intense flooding, bank failures, erosion, and slides, totaling more than $5 million in property damages. During recent recorded history, such events are not uncommon. On January 24-25 1956, 42 inches of rain fell in 30 hours on the northeast side of Kauaʻi leading to 10 feet of floodwaters in the streams between Kīlauea and Anahola. The Hanalei River, which most directly drains the wettest region of Mt. Waiʻaleʻale, overflows its banks at the coast nearly every year.

Dam failures can occur anywhere there is a dam. The threat from dam failures increases as existing dams get older and especially for dams which are not monitored or maintained regularly. More are being built for retention ponds and amenity basins in new developments. Many are above FEMA mapped and are therefore not subject to floodplain regulations. Even when the stream is mapped, the floodplain is not based on a dam failure inundation map, leaving downstream residents unaware of the potential dangers. On March 14, 2006, during a seasaon of unprecedented thunderstorms and heavy rains, the failure of the Kaloko Dam on Kauaʻi killed seven people.

Some years are considerably more damaging than others, for example, November 1955, January 1956, April 1994, and September 1996. In September of 1996 for instance, 9 inches of rain were recorded in 12 hours along the coast, and an uncertain amount fell in the uplands. This event led to flooding of Hanalei town and temporary closure of the Hanalei Bridge, the residents' sole access to the rest of the island. In the western portion of Kauaʻi, the flooding hazard is primarily due to overland flows, especially after storms. Waimea River, for example, has a long record of flooding dating back to 1916 and includes numerous occasions where its channels overflowed after storm-fed precipitation in Waimea Canyon above.

There have been several flooding events in recent years. Heavy rainfall in October 31 to November 2, 2006 across much of Hawaiʻi during the period was the result of two systems. The first being left over moisture from an old front that pooled along the windward sides of the islands. The light easterly wind flow helped push the moisture over windward sections of the islands, resulting in some showers on October 30. By October 31, the destabilized further as an upper level trough of low pressure moved toward Hawaii. The more unstable conditions resulted in locally heavy rainfall that persisted into the afternoon hours of November 1. Rainfall amounts during the period were quite large, especially along windward sections of Kauaʻi and Oʻahu, with some locations receiving well over 15 inches of rainfall. Some locations received over 3 inches in just a matter of 1 or 2 hours. The excessive rains produced flooding over portions of windward Kauaʻi. Earlier in the year, during the unprecedented extended wet period across Hawaiʻi (Feb 19 to April 2), several location in Kauaʻi experienced flashflood and overflow of streams. (http://www.prh.noaa.gov/hnl/pages/events/31Oct2Nov06/HeavyRains.php)

3.2.3 History of Flooding in Kauaʻi

Table 3-8. Kauaʻi Stream Flooding from Atlas of Natural Hazards in the Hawaiian Coastal Zone (Updated).

Island wide stream flood because of heavy rains	
1963 Apr 15	
1968 Nov 28	24” in 24 hours
1972 Apr 15	
1974 Apr 19	10” rain
1975 Jan 30-31	
1978 Oct 30-31	8.5” in 4 hours
1980 June 16	
1981 Aug 3-4	5-10” rain
1981 Dec 25-26	Up to 12” in 24 hours
1982 Feb 11	
1982 Oct 26-30	15-20” in 5 days
1982 Dec 23-25	3-5” rain
1986 Nov 10-11	Flash flooding
1987 Oct 15	Flash flooding
1987 Nov 4	Flash flooding
1988 Jan 28-29	10” rain
1988 Aug 2-11	
1989 Jan 10-12	Flash flooding
1989 Apr 24	
1990 Nov 20	
1992 Feb 13-14	
1993 July 21-23	Flooding Hurricane Dora
2003 Nov 29 - Dec 8	Up to 27.10” rain
2004 Aug 3-4	Up to 8.02” rain due to remants of Darby
2006 Feb 19 - April 2	Up to 138.79” rain
2006 Oct 31- Nov 2	Up to 10.9” rain
Western Watershed **Flooding primarily due to overland flow**	
1963 April 15	2-3 feet
1969 Jan 5	
1975 Dec 1	Kekaha
Wainiha/Lumahai **Since 1956 6 damaging floods of 2-3 feet**	
1956 Feb	40,00cfs, 20’ in 24 hours
1968 Nov/Dec	15” in 24 hours
1971 April 6-7	
1974 April 19	10” rain at Wainiha
1975 Jan 30-31	Wainiha
1978 Jun 7	16.2” in 2 days at Hanakapai Stream
1981 Oct 27-28	Wainiha River
1986 Nov 10-11	Lumahai River
1989 Jul 22-23	Wainiha
Hanalei/Waioli, Waipa Streams	
1868, 1877, 1885, 1905, 1921, 1948, 1952, 1963	serious floods
1893 Feb 14	Flash flood, Kilauea Stream

1946-1963	5 damaging floods
1955 Nov 11-12	26.1" rain, 8 ft. flooding
1956 Jan 24-25	7 ft 44,900 cfs
1967 Dec 9	Hanalei River
1971 Apr 6-7	5ft at Hanalei River
1975 Jan 30-31	Hanalei
1981 Oct 27-28	Hanalei River
1982 Dec 6-7	
1986 Aug 11	Hanalei River
1988 Aug 4-11	
1989 Jul22-23	
1990 Nov16-17	
1994 Apr 12-13	10" Flash flood, mudslide
1996 Sep 7	9" in 12 hrs, Hanalei bridge closed
Kahiliwai/ Anahola	
1914 Sept	2 ft at Anahola Stream
1932 Feb	Anahola Stream
1948 Apr 1	Anahola Stream
1956 Jan 24-25	42" in 30 hrs, 10 flooding at Kahiliwai, Aiani, Kilauea
1964 Dec	Anahola Stream
1965 May	Anahola Stream, 6ft overland flows
1968 Nov 28	24" in 24 hours at Anahola Stream
1990 Nov 16-17	15" rain
1991 Dec 14	20" in 12hrs at Anahola Stream
1992 Feb 13-14	Anahola Stream
1993 Oct 2	3-6" rain flash flood
1994 Apr 13	heavy rain, flash flood
Kapa‘a Stream, Wailua River	
1916 Jan 7	Flash flood
1920 Jan	Wailua River
1940 May 13-14	Wailua River
1955 Nov 11-12	Kapaa Stream, Wailua River 85,000cfs
1956 Jan 24-25	Kapaa Stream, Wailua River
1963 Apr 15	Wailua River
1965 Apr	Kapaa Stream
1967 May	Kapaa Stream, 5ft
1967 Nov 24-27	Wailua River
1968 Dec 29-31	Kapaa Stream, 12,800 cfs, 7ft, 15-20" in 24 hours
1975 Jan 30-31	Wailua River
1981 Oct 27-28	Wailua River
1991 Dec 14	Kapaa, flash flood
Hanamaulu, Nawiliwili, Huleia Streams **Flooding is primarily due to runoff/overland flows**	
1965 Aug 2	4.5" in 1 hour at Hanamaulu Stream
1968 Dec 5	10ft at Hanamaulu, Nawiliwili, Huleia Streams
1975 Jan 30-31	Nawiliwili Stream
1978 Oct 30-31	8.5" in 24 hours at Nawiliwili Stream
Koala/ Poipu **Flooding is due to overland flow**	
1954, 1955, 1957, 1963, thrice 1965, 1968	major floods
1965 Aug 13	Poipu
1972 Apr 15	Poipu

1989 Aug 20-21	Flash flood, Poipu
Hanapepe River, Waihiawa Stream, Kalaheo Gulch	
1879 Jan	Hanapepe
1924-1959	11 damaging floods at Hanapepe River
1949 Dec 17	Flash flood, 4-5 ft at Hanapepe
1963 Apr 15	5-6 ft at Hanapepe River
1967 Nov 24-27	Hanapepe River
1968 Dec 29-31	3-4 ft at Hanapepe
1975 Jan 30-31	
Makaweli, Waimea **Flooding is due to overland flows after storms**	
1916, 1921, 1927, 1942	Major floods
1949 Feb 7	3-8 ft, 48,000cf at Waimea River
1973 Dec 1	
1993 Oct 2	3-6 in, flash flood

Source: Fletcher III, Charles H., E. Grossman, B. Richmond, A.E. Gibbs. 2002. Atlas of Natural Hazards in the Hawaiian Coastal Zone. US Department of the Interior US Geological Survey. CD-ROM. http://pubs.usgs.gov/imap/i2761/. Updated with information from NOAA National Weather Service http://www.prh.noaa.gov/hnl/pages/events/31Oct2Nov06/HeavyRains.php.

3.2.3 History of Flooding in the City and County of Honolulu

The most frequent and severe flooding occurs where steep sloping hillsides abruptly meet flat or low-lying coastal plains, such as those found in Waimanalo, Kailua, Kaneʻohe (November 1992), and Lāʻie (April 1994). The heaviest rainfall during the last decade in Kaneʻohe occurred in October 1991, when 15 inches fell in 48 hours leading to intense flash flooding.

Stream mouths are also commonly susceptible to flooding, especially during marine storm or high wave events, as runoff from streams reach a sea that is partly elevated by the combination of high waves, winds, and storm surges. Some of the largest rainfall counts and most severe flooding events have occurred in the last several years. During the first 15 days of November 1996, record-breaking rainfall occurred along the Waianae Coast, where 21 inches fell in an area where the average annual rainfall is 2 inches. In Ewa, 12.5 inches fell in 7 hours on the 5th of that month, inducing flooding of the low coastal plain. A series of slow moving storms with prolonged rains that saturated the soils of south-central Oahu culminated on New Years Day of 1988 in severe runoff and hillside erosion, resulting in catastrophic damage to stream flood mitigation channels, homes, and roads in ʻĀina Haina and Niu Valleys. Other recent severe events on Oʻahu include October 1981 flooding of Waiawa Stream after heavy rains that lead to $786,000 damage and January 1968 flooding in Pearl City, which caused $1.2 million damage.

The largest waves reach Oʻahu in winter. Along the north shore, it is common to see wave heights between 15-20 feet annually from winter swell causing coastal flooding. Wave heights of 50 feet have been reported (December 1969 and January 1998). Often, winter north and northeast swells wrap around Makapuʻu Point and generate waves at Sandy Beach that are as high as the largest summer surf found there. Trade wind waves can be high, but because of their shorter wavelengths, they have less energy than north and south swell. Trade wind swell has a greater easterly directional component, which enables them to refract around to south and southwest-facing shorelines producing wave heights of 1-4 feet. In the summer, south-facing shorelines receive 4-6 foot swell. South swells tend to have less energy and longer wave periods than winter swells. Hurricane generated waves have exceeded 15 feet along east Oahu and 10 feet on O'ahu's southern shores. Combined with storm surge and high tides, hurricane waves can overwash coastal roads and properties, as they did along the Ka'a'awa and Kane'ohe coasts during Hurricane Fernanda in 1993 and along the Honolulu and Wai'anae coasts during Hurricane Iniki in 1992.

During the last few days of November and the first week of December of 2003, several weather systems combined to bring several rounds of heavy rainfall to many parts of the state. A few locations in the Ko'olau Mountains of O'ahu likely received over 3 feet of rain in just a 10 day period causing flash flooding and stream overruns. (http://www.prh.noaa.gov/hnl/pages/events/wet_stuff/wet_stuff.php)

During August 2-4, 2004 the remnant swirl of Darby caused excessive rainfall in all Hawaiian Islands. On August 3, the remnants moved approached O'ahu, affecting the entire island of O'ahu and dumping several inches of rain in a few hours. A few streams overflowed their banks and minor landslides occurred, both resulting in some road closures. The main effect was significant ponding of water on the roads, which impacted the morning rush hour.

During the late afternoon on October 30, 2004 an area of showers being pushed west by the low level tradewind flow interacted with the Ko'olau Mountains on the windward (east) side of O'ahu. As the air was pushed up over the mountains, the unstable environment allowed those showers to rapidly develop into a thunderstorm and remain focused over a small area of southeast O'ahu. This thunderstorm, locked into place due to the terrain, produced very heavy rainfall totals in just a few hours. The focus of the heaviest rain occurred over the southern portion of the Ko'olau Mountains on O'ahu, resulting in Mānoa Stream overflowing its banks and causing significant flooding in Mānoa Valley, including the University of Hawaii campus. At the height of the heavy rainfall around 7 pm, rainfall rates recorded at the gauge at the Mānoa Lyon Arboretum, in the upper portion of Mānoa Valley, were over 5 inches per hour. These large rainfall rates are estimated to occur with a return rate of almost 50 years. In other words, in any given year, there is only a 2% probability of such a heavy rainfall event like this occurring in upper Mānoa Valley (NOAA National Weather Service, http://www.prh.noaa.gov/hnl/pages/events/ManoaFlood20041030/).

Heavy rainfall in October 31 to November 2, 2006 produced flooding over portions of windward O'ahu and triggered a significant landslide that closed O'ahu's Pali Highway. (http://www.prh.noaa.gov/hnl/pages/events/31Oct2Nov06/HeavyRains.php)

Table 3-9. O‘ahu Stream Flooding from Atlas of Natural Hazards in the Hawaiian Coastal Zone (Updated).

Island wide stream flood because of heavy rains	
1900 Nov. 14	
1921 Jan. 16	
1935 Feb. 27	
1947 Feb. 7	
1948 Jan. 23 – 26	
1949 Jan. 15 – 17	
1951 Mar. 26 – 27	
1954 Jan 21	
1954 Nov. 27 – 28	
1956 Jan. 24 – 25	
1957 Dec. 1	
1958 Mar. 5	
1958 Aug. 6 – 7	
1959 Jan. 17 – 18	
1959 Aug. 4 – 7	
1960 May 12 – 13	
1961 Oct. 27	
1962 Jan. 7	
1963 Jan. 15 – 17	
1964 Dec. 19 – 23	
1965 Feb. 4	
1965 Nov. 10 – 15	
1966 Sept. 10 – 12	
1966 Oct. 10	
1967 Jul. 4 – 8	2 to 3 Inches
1967 Jul. 5 – 18	
1967 Jul. 11 – 21	
1967 Aug. 10 – 14	
1967 Dec. 9	
1967 Dec. 17 – 18	
1969 Dec. 27 – 28	
1972 Aug. 8 – 20	
1974 Apr. 19	
1975 Jan. 30 – Feb. 1	
1975 Nov. 23 – 27	
1976 Feb. 5 – 7	
1976 Nov. 6 – 7	
1978 Jun. 26 – Jul. 3	
1978 Oct. 30 – 31	
1980 Mar. 18 – 19	
1981 Aug. 3 – 4	
1981 Dec. 25 – 26	
1982 Sept. 1	
1982 Oct. 26 – 30	
1982 Dec. 23 – 24	
1984 Dec. 24 – 25	
1985 Jan. 29 – 30	
1986 Nov. 10 – 11	
1987 Jul. 21 – 23	
1987 Sept. 2	
1987 Dec. 11 – 19	
1988 Jan. 28 – 29	
1988 Aug. 2 – 3	
1988 Sept. 26 – 27	
1988 Dec. 5 – 6	

1989 Mar. 1 - 4	
1989 Apr. 24	
1989 Jul. 18 – 20	
1990 Jan. 14 – 22	
1991 Oct. 10 – 15	
1993 Jul. 21 – 23	
1993 Oct. 10	
1994 Apr. 13 – 14	
1996 Nov. 5	
1996 Nov. 15	
2003 Nov 29 - Dec 8	Up to 32.98” rain
2004 Aug 3-4	Up to 9.04” rain due to remants of Darby
2004 Oct 30 - 31	Up to 10.07” rain in 12 hour, Manoa Stream overflowing its bank causing significant damage to UH Manoa
2006 Feb 19 - April 2	Up to 87.18” rain
2006 Oct 31- Nov 2	Up to 22.39” rain
Haleiwa: Since 1874 – 19 Floods	
1932 Feb. 28	Wailua Stream, Flash Flood 26 – 30” in 24 Hrs. at Poamoho, Kikii, Paukauila Stream
1935 Feb 27	20” in 24 Hrs.
1939 Mar. 1 – 2	Lowland Flooding
1939 Oct. 22 – 23	10 – 12” in 24 Hrs.
1956 Feb. 25	Flash Flood, 14” at Wailua
1962 Mar. 13 – 15	Flash Flood
1968 Mar. 13 – 18	12” in 24 Hrs.
1969 Feb. 28	21” in 24 Hrs. at Anahulu, Kaukonahua, Poamoho, Opaeula, Helemano Str.
1974 Apr. 19	Opaeula, Helemano, Poamoho, Kaukonahua River
1976 Feb.5 - 7	
1976 Nov. 6 – 7	
1982 Jan. 6	Waialua
1987 Oct. 11	
Sunset Beach	
1935 Feb. 27	10.24” in 24 Hrs. at Waimea River
1956 Feb. 25	Flash Flood
1962 Mar. 13 – 15	Flash Flood
1968 Mar. 13 – 15	Waimea River; 5,270 cfs
1969 Feb. 1	Waimea River; 3,860 cfs
1996 Nov. 14	Widespread Flooding
1975 Jan. 30 – 31	Flooding
1987 Oct. 11	
1989 Jul. 18 – 20	Waimea River, Sunset Beach
1990 Nov. 20	Waimea River
Kahuku: 7 Major Floods	
1962 Mar. 13 – 15	
1963 Apr. 15	
1982 Feb. 21	Kahawainui
1985 Feb. 14	5 – 10”
Windward Coast	
1918 Apr. 11	Flash Flood, Windward Coast
1924 Oct. 11	Flooding of Lowlands, 11” in 11 Hrs.
1927 Mar. 5 – 6	Flash Flood, Windward Coast
1932 Feb. 13	Flash Flood at Punaluu
1956 Jan. 26	Streams Overflowed
1959 Jan. 17 – 18	Windward Side
1963 Apr. 15	19” in 24 Hrs. at Makaua, Kaaawa, Waiahole Streams
1965 Feb. 3 – 4	Flooding in Lowlands, 18” at Waiahole and Kaaawa Streams

1965 Mar. 31	Flash Flood, 4.5” in 1.5 Hrs. at Punaluu
1965 May 2-3	Flash Flooding, 8.75” in 3 Hrs. at Kaaawa
1971 Dec. 31	Kaluanui Stream, Sacred Falls, Waiahole
1982 Jan. 6	Flash Floods
1982 Sept. 1	Flash Floods
1984 Mar. 26 – 28	6 – 15”
1985 Feb. 14	5 – 10”
1985 May 6	8 – 10”
1985 Nov. 18	
1986 May 10	
1986 Sept. 28	
1987 Mar. 24	Flash Flood at Sacred Falls
1987 May 5	
1987 Jul. 21 – 23	
1992 Oct. 11	Windward Oahu, Minor Flash Flooding
1994 Apr. 12	6” in Kahuku, Flash Flooding
Kahaluu: Since 1936 – 20 Floods	
1965 Feb. 4	3 Ft.
1965 May 2 – 3	3 – 4 Ft.
1970 Nov. 24 – 26	11.5” in 4 Hrs. from Kahaluu to Waimanalo
1976 Feb. 5 - 7	
1994 Apr. 13	Hauula to Kahaluu, Flash Floods, Heavy Rains, Road Closures
Kaneohe: Since 1872 – 9 Major Floods	
1963 Apr. 15	Kaneohe
1965 Feb. 4	Kamooalii Stream
1965 May 2 – 3	5,920 cfs at Haiku, Lolekaa
1969 Feb. 1	4 – 6 Ft.
1970 Nov. 24 – 26	
1991 Oct. 15 – 16	Kaneohe, 15” in 48 Hrs, Flash Flooding
1992 Nov. 26	Kaneohe, Heavy Rainfall, Flooding
Kailua	
1951 Mar. 26 – 27	
1963 Mar. 6	
1982 Jul. 23	Flash Flooding
1987 Dec. 31 – Jan 1	Slow Flood, 2 – 5 ft at Kawainui Marsh
Waimanalo	
1957 Feb. 7	
1958 Mar. 5	13.8” in 24 hrs., 3 Ft.
1963 Mar. 6	
1967 Dec. 9	
1967 Dec 17 - 18	
1970 Nov. 24 – 26	11.5” in 4 Hrs.
1976 Feb. 5 – 7	
1982 Jan. 6	
East Oahu: 9 Major Floods	
1957 Jan.	Waialae, Niu Valley
1957 Feb. 7	Aina Hina
1958 Mar. 5	2170 cfs at Waialae Iki Str., Wailupe Str.
1967 Aug 9	Wailupe
1967 Dec. 17 – 18	3600 cfs at Waialae Iki Str., 11” in 8 Hrs at Niu Valley, Aina Hina, Kuliouou
1987 Dec.31 – Jan. 1	Flash Flooding at Waialae Iki Str.
1990 Feb. 28 – Mar. 1	Niu Valley
Manoa and Palolo: 12 major Floods	
1904 Feb. 10	Manoa
1918 Dec. 3 – 4	Manoa
1927 May 16	Manoa
1930 Apr. 11	Palolo

1948 Nov. 17	Manoa, Palolo
1950 Dec. 3	Manoa
1977 Apr. 19	Manoa, Palolo
Honolulu	
1898	Flash Flood at Honolulu
1911 Feb. 4 – 5	Flash Flood at Waikiki, Moiliili
1917 Mar. 19	Flash Flood at Honolulu
1921 Jan. 16	
1927 Dec. 27	Flash Flood
1932 Feb. 13	Puunui
1943 Jan 4 – 5	Kaimuki, Kahala, Diamond Head, Waikiki
1957 Feb. 7	
1965 May 2	
1968 Jan. 27	
1968 Oct. 19	
1971 Feb. 1	
1974 Jul. 17	Nuuanu, Puunui Str.
1975 Nov. 23 – 25	11” in 4 Days
1976 Feb. 5 – 7	
1982 Dec. 23 – 24	
1983 Feb. 23	Nuuanu
1985 Jul. 17	
1991 Sept. 21	Kalihi to Hawaii Kai, Street Flooding
1992 Oct. 21	Honolulu to Kaimuki, Localized Minor Flash Flooding
1993 Oct. 25	Honolulu, 2 – 4” of Rain, Thunderstorms, Flash Flooding, Street Flooding
1996 Nov. 14	Honolulu, Widespread Flooding
2004 Oct 30	Manoa, Widespread Flooding - Up to 10.07” rain in 12 hour, Manoa Stream overflowing its bank causing significant damage to UH Manoa
Pearl City and Barbers Point	
1879	Waikele, Honouliuli, Kipapa Str.
1904 Feb. 10	Pearl City, Ewa
1921	Waikele, Kipapa, Honouliuli Str.
1935 Feb. 27	Waikele, Kipapa Str.
1949 Dec. 19	Ewa
1954 Nov. 28	Waiawa Str, 13600 cfs, Waikele
1956 Feb. 25	Waiawa Str.
1958 Mar. 5	Pearl Harbor
1960 May 14	3710 cfs at Halawa Str.
1963 May 14	1 Ft. at Pearl City
1967 May 30	Halawa Str.
1967 Aug. 2 – 11	Kipapa, Waiawa Str.
1967 Dec. 9	Pearl City
1968 Jan. 5	6 Ft. at Waiawa, Honouliuli
1972	Honouliuli Str.
1981 Oct. 27 – 28	Waiawa Str.
1985 Oct. 23	
1987 Sept. 2	Pearl City, Waipahu
1996 Nov. 5	Ewa, 12.5” in 7 Hrs.
Waianae	
1927 Dec. 27	Flash Flood at Waianae, Wailuku
1954 Nov. 24	Makaha Str.
1962 Mar. 13	Makaha Str.
1964 Dec 12, 23	Makaha Str.
1965 Nov. 13	Makaha Str.
1976 Feb 5 – 7	Waianae
1985 Jan. 29 – 30	Nanakuli, Waianae
1991 Sept. 8	Maili Area, Minor Damage

1991 Oct. 15 – 16	Nanakuli, 15” in 48 Hrs, Flash Flooding
1996 Nov. 5	Record Breaking 21” Rain for Nov. 1 – 5 (Average in 2”)
1996 Nov. 14	Flash Flood, Mudslide
Wahiawa	
1994 Jul. 18	4.5” in 6 hrs.
1989 Feb. 10 – 11	
1990 Mar. 6	Heavy Rain
1992 Oct. 14	Wahiawa to Wailua, Funnel Clouds and Flash Floods
1994 Apr. 12	6” in Wahiawa and on the North Shore, Flash Flooding

Source: Fletcher III, Charles H., E. Grossman, B. Richmond, A.E. Gibbs. 2002. Atlas of Natural Hazards in the Hawaiian Coastal Zone. US Department of the Interior US Geological Survey. CD-ROM. http://pubs.usgs.gov/imap/i2761/. Updated with information from NOAA National Weather Service http://www.prh.noaa.gov/hnl/pages/events/31Oct2Nov06/HeavyRains.php.

3.2.4 History of Flooding in Maui County

Stream flooding on Maui is not only common, but is also the very agent responsible for making it famous as the Valley Island.

Annual rainfall is greatest (360 inches) at the summit of west Maui and nearly as high (280 inches) along the eastern flanks of east Maui just below the trade wind inversion. Rainfall is lowest (<15 inches) in the vicinity of Kihei and Lahaina.

Flooding in areas around Lahaina and Kihei are in part a result of the abrupt transition in slope at the coastline and the behavior of flash flooding. Many flash floods in these areas occurred after heavy rainfall in higher elevations - in some cases equaling the average annual maximum, like in December 1988.

The north central portion of Maui and the Hāna coast have the greatest stream flooding histories. Nearly once a decade, water sheets into the urban centers of Kahului and Wailuku (e.g., November 1950 and 1960). Along the road to Hāna temporary road closures are common due to flash floods and mudslides from the steeper slopes of East Haleakala.

In addition, the Lahaina region and Kihei are vulnerable to standing surface water flooding. This may interrupt transportation and damage low elevation buildings. Standing surface water develops after intense rainfall events where poor soil permeability and urbanization prevent adequate drainage and temporarily disrupting transportation.

Waves from north and northwest swell tend to be highest on an annual basis and generally occur between October and March. Wave heights associated with these swells range between 5-10 feet (Ka‘anapali) and 10-20 feet (Honolua Bay, Waihe‘e to Paia).

Occasionally, waves of 25 feet and greater occur over the deep offshore reefs of the North Shore. Two of the largest wave events occurred February 1993 and January 1998, when waves reached heights of 30 and 40 feet, respectively.

The southern shores of Maui are partly protected from south swell in summer by the islands of Kahoolawe and Lanai. Even so, wave heights range between 4 and 6 feet and, at times, reach 8-10 feet. During winter months, Kona Storm waves can reach 5 feet. Trade wind waves, usually between 3 and 4 feet, impact the eastern shores 70% of the time.

In the summer months, tropical storms and hurricanes can generate wave heights of 10-20 feet along any portion of coast on Maui. Hurricanes Susan, Ignacio, and Estelle generated 10-15 foot waves along the north and east shores. Along the west shore, Hurricane Emilia caused wave heights of 6-10 feet.

Fortunately for Maui, much of its coastline has wide fringing reefs that dissipate wave energy offshore of its northern and western shores, where wave heights are highest.

Also, relative to the other islands, there are only a few locations where development along the shore is subject to direct impact by high waves. Unfortunately, however, areas important for tourism and commerce such as Lahaina, Ka‘anapali, Honokōwai, Olowalu, Kīhei, and Kahului are sited on low coastal plains, and so experience periodic wave overwash, causing rapid erosion and temporarily disrupting transportation.

Several storm events in recent years have caused flash flooding in Maui. During November 29 -December 8, 2003 several weather systems combined to bring several rounds of heavy rainfall to many parts of the state. In December 1, 2003, some locally heavy rains around Olowalu, Maui with radar estimating near 10 inches caused roads flooding in the area. (http://www.prh.noaa.gov/hnl/pages/events/wet_stuff/wet_stuff.php) Heavy rainfall in October 31 to November 2, 2006 produced flooding over portions of windward O‘ahu. Along with O‘ahu, the thunderstorms brought one last round of flooding to portions of and then to Moloka‘i and Maui (NOAA National Weather Service, http://www.prh.noaa.gov/hnl/pages/events/31Oct2Nov06/HeavyRains.php).

Table 3-10. Maui County Stream Flooding from Atlas of Natural Hazards in the Hawaiian Coastal Zone (Updated).

Moloka‘i and Lāna‘i - Island wide stream flood because of heavy rains	
1971 Jan 27-28	Storm, flooding
1980 Jan 6-14	Flooding
1981 Oct 27-28	Flash floods
1981 Aug 3-4	Flooding
1981 Dec 25-26	Flooding
1982 Mar 17	Flooding
1982 Mar 30-31	Flooding
1982 Aug 14-16	H Kristy, flash floods
1983 Dec 24-25	Flash floods
1984 Dec 24-25	Flash floods
1985 Feb 14	Flooding

1985 Oct 17-18	Flash flooding
1986 Nov 10-11	Flash floods
1987 Apr 21-22	Flash floods
1987 May 5-6	Flooding
1988 Sep 26-27	Flooding
1988 Nov 4-5	Flooding, up to 10"rain
1988 Dec 5-6	Flooding, over 10" rain
1989 Feb 10-11	Flooding
1993 Jul 21-23	Flooding, remnants of H Dora
2003 Nov 29 - Dec 8	Up to 6.46" rain
2004 Aug 3-4	Up to 1.39" rain due to remants of Darby
2006 Feb 19 - April 2	Up to 14.93" rain
2006 Oct 31- Nov 2	Up to 6.51" rain
Kaunakakai, Molokai	
1950 Nov 30	Flash flooding at Kaunakakai
1961 Oct 31-Nov 3	Storm, flash flooding
1997 Jan 19-20	Street flooding
Kamalo, Molokai	
1961 Oct 31-Nov 3	Flash flooding at Kamalo
1965 Apr 13	Flash flooding along SE Molokai
Halawa, Molokai	
1961 Jan 1	Flooding, 10,900 cfs at Halawa Str
1961 Oct 31-Nov 3	Flooding at Kawela Gulch
Kualapuu Gulch, Molokai	
1916 Jan 1	Flash floods at Kualapuu Gulch
Halepalaoa Landing, Lanai	
1985 Oct 17-18	Flash flooding on Lanai
Maui - Island wide stream flood because of heavy rains	
1900 Nov 14	Flash flood
1906 Dec 23	Flash flood
1916 Jan 14	Flash flood
1918 Apr 18	Flash flooding
1930 Nov 18	Flash flooding
1946 Jan 2	Flood
1946 Dec 20	Flash flooding
1948 Apr 2	Flash flood
1950 Nov 30	Flash flood
1951 Feb 22	Flash flood
1960 May 12-13	Flooding
1961 Oct 24	Flash flooding
1963 Mar 13	Flooding
1965 Jan 23	Flash flood
1968 Mar 13-16	Flooding
1968 Nov 28	Minor Flooding
1971 Jan 28	Flooding
1974 Apr 19	Flash flooding
1980 Jan 6-14	Flooding
1981 Aug 3-4	Flooding
1981 Oct 27-28	Flooding
1982 Mar 30-31	Flooding
1982 Apr 1-3	Flooding
1982 Jul 16-17	Flooding
1982 Dec 23-24	3-5"rain
1984 May 23	Minor flash floods
1984 Dec 24-25	Flash flooding
1985 Oct 17-18	Flash floods
1985 Nov 18	Minor flash floods
1986 Feb 15	Flash floods

1986 Nov 10-11	Minor flash flooding
1987 Apr 21-22	Minor flash flooding
1987 Apr 26	Flash flooding
1987 May 5-6	10” rain, flash flooding
1988 Jan 28-29	Flash floods
1988 Nov 4-5	Extensive flooding
1988 Dec 5-6	Flash flooding
1989 Feb 10-11	Minor flash flooding
1989 Mar 1-4	Minor flash floods
1990 Jan 14-22	Up to 20” rain, flooding
1991 Jan 27	Flooding
1991 Mar 19-21	Flooding
1993 Jul 21-23	Flooding, remnants of H Dora
2003 Nov 29 - Dec 8	Up to 22.74” rain
2004 Aug 3-4	Up to 5.05” rain due to remants of Darby
2006 Feb 19 - April 2	Up to 41.93” rain
2006 Oct 31- Nov 2	Up to 14.06” rain
West Maui	Honokawai and Lahaina are frequently flooded. Since 1879, 19 damaging floods occurred in the Lahaina area.
1916 Jan 26	Lahaina and Olowalu flooded
1950 Nov 30	Flash flooding at Lahaina
1960 May 13	Kahoma Stream
1961 Oct 31-Nov 3	West Maui, Kahoma Stream
1967 Mar 17-18	7” in 5.5 hours at West Maui
1971 Jan	Lahaina, Kauaula Stream (Hale, Cannery, Kelawe Camp)
1972 Feb 24	5-8” in 5 hours at West Maui, Lahaina
1974 Nov 21	Kaanapali, Honokawai
1987 May 5-6	Flash flooding at Lahaina
1988 Dec 5-6	Over 10” of rain
1997 Jan 19-20	Flooding Lahaina
Southwest Maui	Frequent flooding of Kulanihakoi, Waipuilani, Keokia, and Waiakoa streams
1916 Jan 26	Kihei
1930 Jan 29	Flash flooding at Kulat, Kihei
1951 Feb 22	Kihei
1955 Dec 21	Kihei
1967 Mar 24	6” in 6 hours at Kihei
1968 Jan 28	Kihei
1971 Jan 27-28	6 ft at Kihei
1988 Dec 5-6	Over 10” rain at Kihei
South Slope Haleakala	Historical flooding of streams between Kipahulu and Nuu
1968 Apr 15-16	
1986 Nov 10-11	
Windward Haleakala	Makawao, Kaupakulua, Wailua and Hana frequently flooded by sheetflows
1965 Apr 25-28	Flash flood at Hana
1968 Apr 15-16	East Maui esp. Honomaele Stream
1981 Oct. 27-28	Road to Hana
1982 Mar 30-31	Road to Hana
1982 Jul 21-22	Flash flooding
1982 Aug 1	Flash flooding esp. Kaanapali
1984 May 23	Minor flash flooding, road to Hana
1987 Feb 15	8-10” at Hana area
1987 May 5-6	10”
1988 Mar 24	Road to Hana
1991 Mar 19-21	Road to Hana
1992 Nov 26-27	Severe flooding
1993 Oct 23	Flash flood, mudslide
1994 Apr 12-13	Flash flood, mudslide

North Central Maui	Wailuku and Iao Stream are frequently flooded. Kahului frequently inundated by sheetflow.
1900 Nov 14	Kahului
1903 Feb 13	Flash flood at Wailuku
1916 Jan 14	17000 cfs at Iao Valley
1920 Dec 24	Storm, flooding at Wailuku
1930 Nov 18	Iao Stream
1948 Jan ?	Iao Stream
1950 Nov 30	Flash flooding at Iao Valley, Wailuku
1950 Dec 3	7550 cfs, 5" rain in 2 hours at Iao Stream
1961 Nov 2	5700 cfs at Iao Stream
1965 Feb 4	Sheetflow
1971 Jan 27-28	5820 cfs at Iao Stream, 2 ft at Paia
1972 Feb 8	3.5" in 1 hr at Wailuku
1978 Nov 12	Flash flooding at Iao Valley, Kahului
1982 Mar 30-31	Iao Valley
1987 Mar 5-6	Over 10" rain, flash flooding at Wailuku, Kahului
1989 Feb 3-5	Flash flooding near Haiku
1994 Apr 12-13	Flash flood, mudslide
Northwest Maui	
1961 Nov 2	Flash flooding at NW Maui, Napili, Honolua
1964 Dec 19	NW Maui
1967 Mar 17	Napili Bay
1967 Mar 24	Napili Bay, heavy rains
1968 Mar 13-16	24" in 48 hours at Napili Beach, Honolua, Paakea

Source: Fletcher III, Charles H., E. Grossman, B. Richmond, A.E. Gibbs. 2002. Atlas of Natural Hazards in the Hawaiian Coastal Zone. US Department of the Interior US Geological Survey. CD-ROM. http://pubs.usgs.gov/imap/i2761/. Updated with information from NOAA National Weather Service http://www.prh.noaa.gov/hnl/pages/events/31Oct2Nov06/HeavyRains.php.

3.2.5 History of Flooding in the County of Hawai‘i

According to the data from the last 50 years, on average a damaging flood event occurs on the Big Island every 2 years. During this past 50 years, however, the threat due to stream flooding has increased dramatically because of the risk taken to develop extensively in flood prone areas. Flooding along the wet, windward side of the island is expected due to high annual rainfall (300 inches on the slopes of Mauna Kea above Hilo).

Most of the flooding that has caused damage has been flash flooding during extreme rainfall events that bring about sheet flow between stream channels. In addition, the soils along the Hamakua Coast readily absorb precipitation - thereby facilitating mudslides and landslides. The Hilo and Puna areas are probably the most frequently flooded and hardest hit by flash floods on Hawai‘i Island and perhaps in the state. The latest severe flooding occurred in November 2000.

The Kohala Coast has had a long and active history of flooding largely due to flash flooding and intense storms. During the last 3 years, the South Kohala and Waikaloa areas have experienced intense flash flooding that has caused considerable damage. Kīlauea and Hualalai volcanoes are located in more arid regions but occasionally do receive intense rainfall that causes flash floods downslope. Annual rainfall ranges between to below 10 and 20 inches in the arid regions of Kawaihae and South Point. The young lavas that comprise the coastal terraces of Mauna Loa, Kīlauea, and portions of Hualalai, are very porous. Often heavy precipitation simply infiltrates into the rock and flows toward the sea in underground streams. As a result, stream flooding is generally less of a hazard on the younger coastlines. Flash floods, however, do happen on the slopes of Kīlauea, Hualalai, and Mauna Loa. During these times of intense rainfall, overland runoff will occur.

On the Island of Hawaiʻi, high waves (10-20 feet) arrive from north swell each winter. Occasional extreme wave events do occur. The enormous north swells of February 1993 and January 1998 brought 20-30 foot waves to the north facing shores. Overwash of the Hilo breakwater and flooding of the coastal roads near Hilo, caused damage in November 1996 and January 1998. The summer south swell generally ranges 4-6 feet. Significant south swells also occur, such as in July 1986 and June 1995, producing 8-12 foot surf along southern shores. Aliʻi Drive in Kailua town, for example, is located particularly close to the ocean in many places and suffers periodic overwash. High waves of 6-8 feet can be produced by well-developed trade wind swell, but usually trade wind waves are 2-4 feet. Tropical storms and hurricanes bring damaging high waves of 10-30 feet to any and all shorelines.

Homes were flooded, roads closed, and emergency shelters filled as families flocked to find help during the floods that affected the Big Island from October 28-November 3, 2000. According to the National Weather Service, 26.22 inches fell at Hilo airport in 24-hours on November 1, 2000. The previous record was 22.3 inches on February19-20,1979. Damage in Hawaiʻi County was estimated to be $20 million. Civil Defense Deputy Bruce Butts said 77 businesses and as many as 300 homes were damaged. At Pahala in the Kaʻū District, two bridges on the Hawaii Belt Road were severely damaged. On November 3, Governor Cayetano declared the islands of Hawaii and Maui a disaster area, which authorizes use of major disaster fund, relocation and rehabilitation, housing relief, commercial and personal loan program, and relief to farmers.

On November 9, President Clinton declared Hawaiʻi County a federal disaster area, which authorized federal assistance. More than 1,131 Hawaiʻi Island flood victims registered for assistance through FEMA's toll-free teleregistration number since November 30, 2000. The US Small Business Administration (SBA) approved $2,210,000.00 in low interest disaster loans. For more information on Federal disaster recovery on Hawaiʻi Island, see the County of Hawaiʻi Hazard Mitigation Plan.

During August 2-4, 2004 as the remnant swirl of Darby moved closer to the unstable region, thunderstorms began to develop. The first round of thunderstorms occurred just north and east of the Big Island on August 2. That night, additional showers and thunderstorms formed across parts of the Big Island, particularly the normally dry Kona side. Rainfall amounts of 2 to 5 inches over a few hours were reported, and this led to flooding and closures of several roads.

Table 3-11. Hawai‘i County Stream Flooding from Atlas of Natural Hazards in the Hawaiian Coastal Zone (Updated).

Hawai‘i - Islandwide stream flooding because of heavy rains	
1959 Aug 4-7	H Dot
1979 Feb 19-20	Flooding
1979 Dec 14-18	Flooding
1980 Mar 6-25	Episodes of flooding
1981 Oct 27-28	Flash flooding
1982 Jul 21-22	TD Daniel, flash flooding
1984 Dec 24-25	Kona storm, flooding
1986 Apr 8	Flooding
1986 Nov 10-11	Flooding
1987 Jul 21-23	Flooding
1987 Dec 11-19	Flooding
1988 Mar 14-18	Flooding
1988 Aug 4-8	H, flooding
1989 Feb 3-5	Flooding
1989 Mar 1-4	Flooding
1989 Jul 18-20	TS Dalilia, flooding
1990 Jan 14-22	Flooding
1992 Sep 14	TS Orlene, flooding
1992 Nov 29	Widespread flooding
1993 Jul 21-22	TS Dora, flooding
2003 Aug 31 - Sep 1	6 to 10” rain due to Jimena
2003 Nov 29 - Dec 8	Up to 11.01” rain
2004 Aug 3-4	Up to 5.56” rain due to remants of Darby
2006 Feb 19 - April 2	Up to 54.72” rain
2006 Oct 31- Nov 2	Up to 3.38” rain
Kohala	
1918 Apr 9-10	Flash flooding
1936 Jan 17	Flash flooding at N. Hi
1966 Nov 20	Flash flooding at S. Kohala
1967 Jan 11	Flooding
1982 Aug 9-10	Flash flooding
1983 Dec 24-26	Flooding
1986 Feb 16	Localized flooding
1986 Apr 8	Flooding at Waimea, Kohala
1989 Feb 3-5	Flash flooding at Pahala
1989 Apr 28-29	Flash flooding at Waimea
1991 Aug 5-7	Flash flooding
1996 Sep 8-9	Flash flood S. Kohala and Waikaloa
1997 Jan 5	Widespread floods Waikaloa Village
Kailua-Kona	
1918 Apr 9-10	Flash flood at Kona sugar mill
1922 Oct 22	Flash floods at South Kona
1930 Jan 25	Holualua reservoir burst, flash floods
1961 Oct 30	Flash floods at South Kona
1963 Apr 29	Flash floods at Kaimaliu
1965 Sep 25	Capt. Cook, Kaimaliu
1966 Oct 3-5	Flash floods at Capt. Cook & Holualua
1967 Oct 12	Overland flow at Hookena
1967 Oct 24	N. Kona
1968 Jul 17	Local flash flooding at Kealakekua
1968 Oct 3	Flash floods at N. Kona
1974 Oct 15	Flooding Kaloloa to Honaunau, 4.5” in 7 hrs.
1976 Apr 26	Flash flooding Honaunau
1982 Mar 17	Minor flooding at Kona

1985 Sep 29	Flash flooding Capt. Cook to Kealakekua
1985 Nov 19	
1986 Feb 16	Localized flooding at N. Kona
1989 Feb 3-5	Flash flooding at S. Kona
1992 Sep 17	Heavy thunderstorms, minor flooding
1996 Jun 22	2.1” in 1 hr., widespread flooding
1997 Jan 5	Widespread floods, Captain Cook to Kona
South Point	
1967 Nov 26-27	Severe flooding at Naalehu
1979 Feb 19-20	Naalehu & Pahala, 22.3” in 24 hrs.
Ka‘ū	
1917 Mar 19	Flash flood
1945 Apr 8	Flash flood
1962 Mar 13-15	Overland flow at Palaha
1980 Mar 18	Flooding
1982 Jul 16-17	TS Emilia
1982 Aug 1	TS Gilma
1985 Nov 19	Minor flash flooding in Kau district
1986 Nov 8	Flash floods, 10” rain
1989 Jul 18-20	TS Dalilia flooding
1990 Jan 14-22	Flooding, over 20” rain
1990 Sep 14-28	Flooding
1990 Nov 18-20	Flooding, 30” rain
Hilo/Puna	
1928 Oct 1	Flash flood of Wailuku R.
1966 Jul 25	Sheet flow
1967 Aug 2-11	Flash flood, 12” rain
1971 Apr 23	Flash floods, 9.66” in 24 hrs.
1979 Feb 19-20	Flooding at Hilo, Keeau, Pahoa, Kurtistown
1980 Mar 18	Flooding
1980 Sep 20-22	Flooding
1982 Mar 30-31	Flooding, 10” rain
1982 Jul 16-17	TS Emilia, flash flooding
1982 Jul 23	Flash flooding, 29” rain in July
1982 Aug 1	TD Gilma, flash flooding
1984 Nov 3-4	Flooding, 4-6” rain
1985 Sep 25	Flash floods
1986 Apr 3	Flash floods
1986 Sep 26	Flash flooding, 6-10” rain
1986 Nov 8	Flash flooding, 10” rain
1987 Oct 1	Flooding, 10-15” rain
1988 Aug 4-8	H Fabio, flooding in Hilo and Kurtistown
1990 Nov 18-20	Flooding, 30” rain
1991 Aug 3-4	Flash flood, 11” at airport
1992 Sep 14	TS Orlene, widespread flood
1993 Oct 3	5-7” rain Puna and Hilo
1994 Apr 11-12	Floods, landslides
2000 Nov 1-2	Flooding, landslides, 25” in 24 hrs.
Hamakua Coast	
1890 Dec 9	Flash floods at Hamakua, Honokaa
1902 Mar 6	Flash floods at Hamakua
1965 Aug 4-5	Sheet flows
1982 Jul 16-17	Flash flooding at Hamakua
1982 Aug 1	TD Gilma, flash flooding
1982 Aug 9-10	TS John, flash flooding at Honokaa
1983 Oct 26	Hamakua Coast
1984 Feb 8	Flooding
1985 Mar 11	Flash flooding
1986 Mar 16	Flash flooding

1986 Apr 3	Flash flooding
1986 Apr 8	Flooding
1986 Sep 26	Flash floods, 6-10" rain
1987 May 5-6	Extensive flash flooding, over 10" rain
1987 Oct 1	Flooding, 10-15" rain
1987 Nov 21	Flash flooding
1988 Mar 14-18	Flooding, 5-10" rain
1989 Apr 28-29	Flooding at Honokaa
1989 Aug 20-21	Minor flash floods
1990 Dec 18-20	Flooding
1991 Aug 5-7	Flooding
1994 Apr 11-12	Floods, landslides
Waipi'o Valley	
1902 Mar 6	Flash flooding
1972 Aug 18- Sep 3	Flash flooding
1978 Dec 6	Flooding
1979 Dec 14-18	Severe flooding
1989 Apr 4-9	Flooding
1991 Aug 5-7	Flooding

Source: Fletcher III, Charles H., E. Grossman, B. Richmond, A.E. Gibbs. 2002. Atlas of Natural Hazards in the Hawaiian Coastal Zone. US Department of the Interior US Geological Survey. CD-ROM. http://pubs.usgs.gov/imap/i2761/. Updated with information from NOAA National Weather Service http://www.prh.noaa.gov/hnl/pages/events/31Oct2Nov06/HeavyRains.php.

3.2.6 Flood Insurance Rate Maps

Under the National Flood Insurance Program (NFIP), FEMA is required to develop flood risk data for use in both insurance rating and floodplain management. FEMA develops these data through Flood Insurance Studies (FIS). In FISs, both detailed and approximate analyses are employed. Generally detailed analyses are used to generate flood risk data only for developed or developing areas of communities. For undeveloped areas where little or no development is expected to occur, FEMA uses approximate analyses to generate flood risk data.

Using the results of the FIS, FEMA prepares a Flood Insurance Rate Map (FIRM) that depicts the Special Flood Hazard Areas (SFHAs) within the studied community. SFHAs are areas subject to inundation by a flood having a one percent chance or greater occurring in any given year. The floodplain management and insurance requirements of the NFIP are based on the 100-year flood (or base flood), which is the national standard. The FIRMS show base flood elevations (BFEs) and flood insurance risk zones. The FIRM also shows areas designated as a regulatory floodway. The regulatory floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 100-year flood discharge can be conveyed without increasing the BFE more than the specified amount. Within the SFHAs identified by approximate analyses, the FIRM shows only the flood insurance zone designation.

FEMA Flood Insurance Rate Map Definitions

Zones VE and V1-V30
Zones VE and V1-V30 are the flood insurance rate zones that corresponds to the 100-year coastal floodplains that have additional hazards associated with storm waves. Whole-foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone.

Zone A
Zone A is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no base flood elevations or depths are shown within this zone.

Zones AE and A1-A30
Zones AE and A1-A30 are the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by detailed methods. In most instances, whole foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone.

Zone AH
Zone AH is the flood insurance rate zone that corresponds to the areas of 100-year shallow flooding (usually areas of ponding) where average depths are between 1 and 3 feet. Whole-foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone.

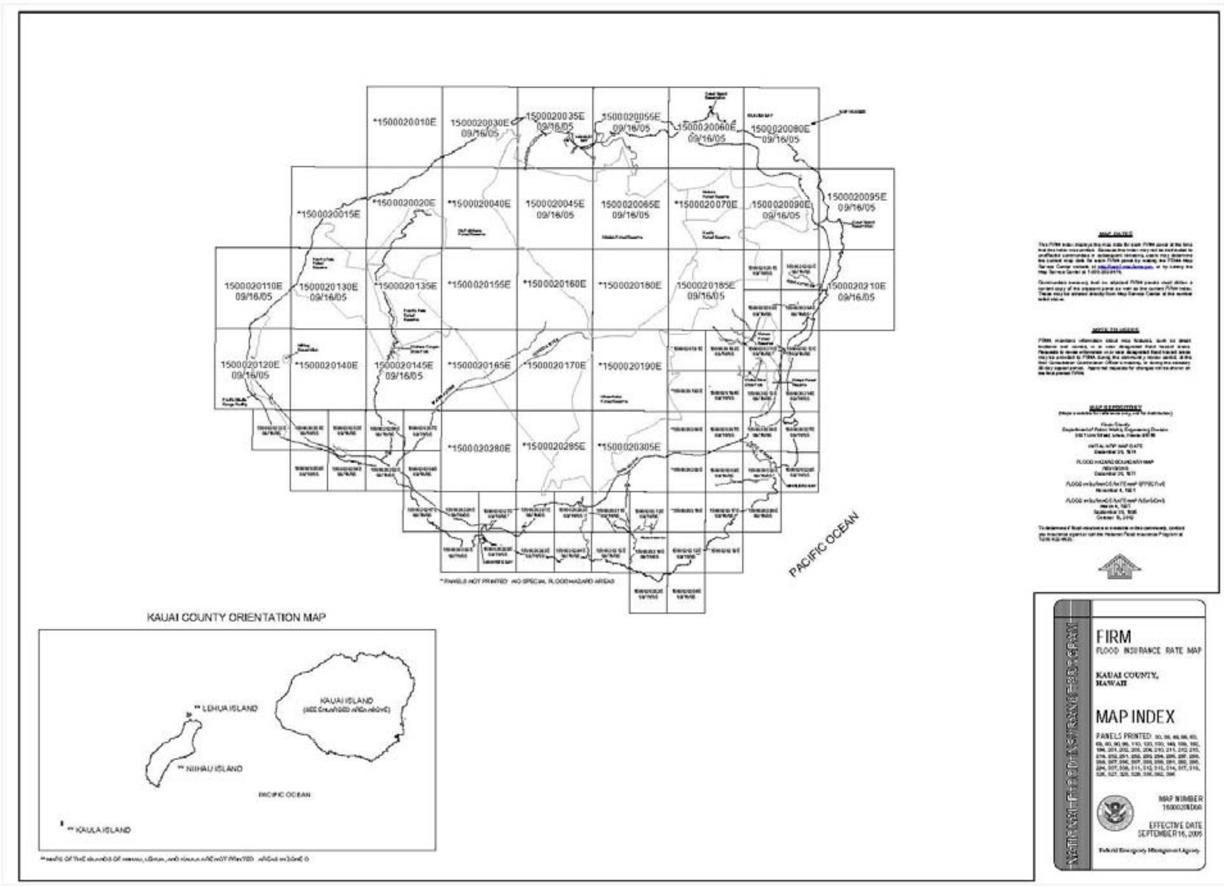
Zone AO
Zone AO is the flood insurance rate zone that corresponds to the areas of 100-year shallow flooding (usually sheet flow on sloping terrain) where average depths are between 1 and 3 feet. Average whole-depths derived from the detailed hydraulic analyses are shown within this zone

Zones B, C, and X
Zones B, C, and X ~~is~~ are the flood insurance rate zone that corresponds to areas outside the 1-percent annual chance floodplain, areas of 1-percent annual chance sheet flow flooding~~, and to areas of 100-year flooding~~ where average depths are less than 1 foot, areas of 1-percent annual chance stream flooding where the contributing drainage area is less than 1 square mile, ~~and~~ or areas protected from the 1 percent annual chance ~~100-year~~ flood by levees. No base flood elevations or depths are shown within this zone.

Zone D
The Zone D designation is used for areas where there are possible but undetermined flood hazards. In areas designated as Zone D, no analysis of flood hazards has been conducted.

The digital FIRM maps (dFIRMs) for the City & County of Honolulu and Kauaʻi County are available. The dFIRM index for Kauaʻi is shown below. The counties have the detailed parcel maps and FIRM Maps that can be used in more detailed planning. Kauaʻi County has the following web portal for building and permitting that enables access to all of the counties dFIRMS: http://www.kauai.gov/portals/0/pw_eng/design-permitting/flood_zone_maps/IndexPanel.pdf. A person can click on a section of the following map and get detailed access.

Figure 3-3. Kaua'i County dFIRM Panels Online.



The City & County of Honolulu also has GIS data available for the public on their permit and planning website, (http://gis.hicentral.com/website/parcelzoning/viewer.htm). The GIS maps on the site enable the following applications to be shown on maps that can be zoomed in by parcel to see these layers with land use, zoning, and utilities.

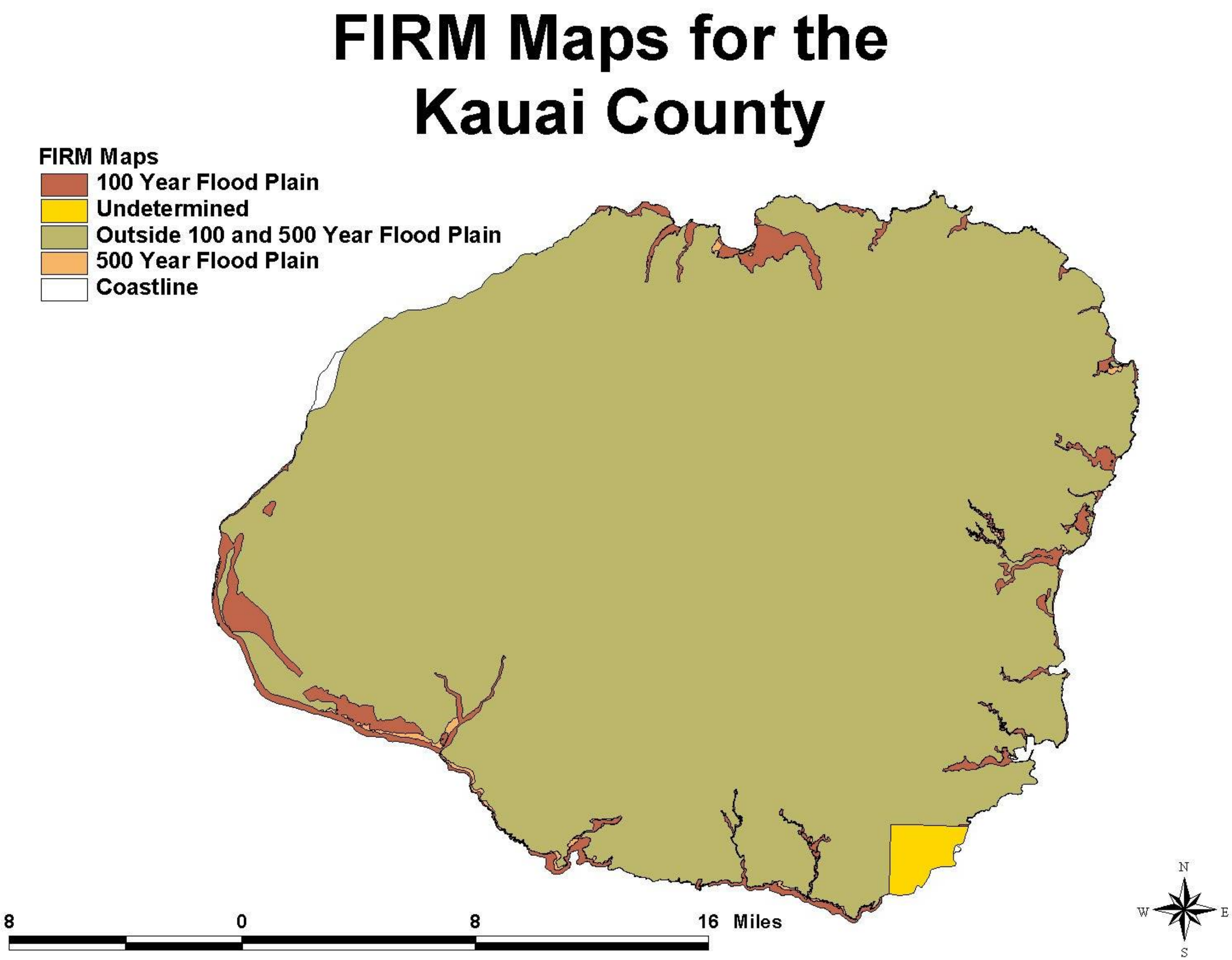
Table 3-12. GIS Hazard Layers in the System.

Topography 5'	☐ Flood	☐ Neighborhood Board	☐ Special Management Areas
☐ Flood Elev Lines	☐ Topography 5'	☐ Flood Elev Polys	☐ USGS Quad Map Mosaic (Oahu)
☐ Census Blocks 2000	☐ Council Districts	☑ FIRM Flood Sheets	☑ **Tsunami Evac. Zones**

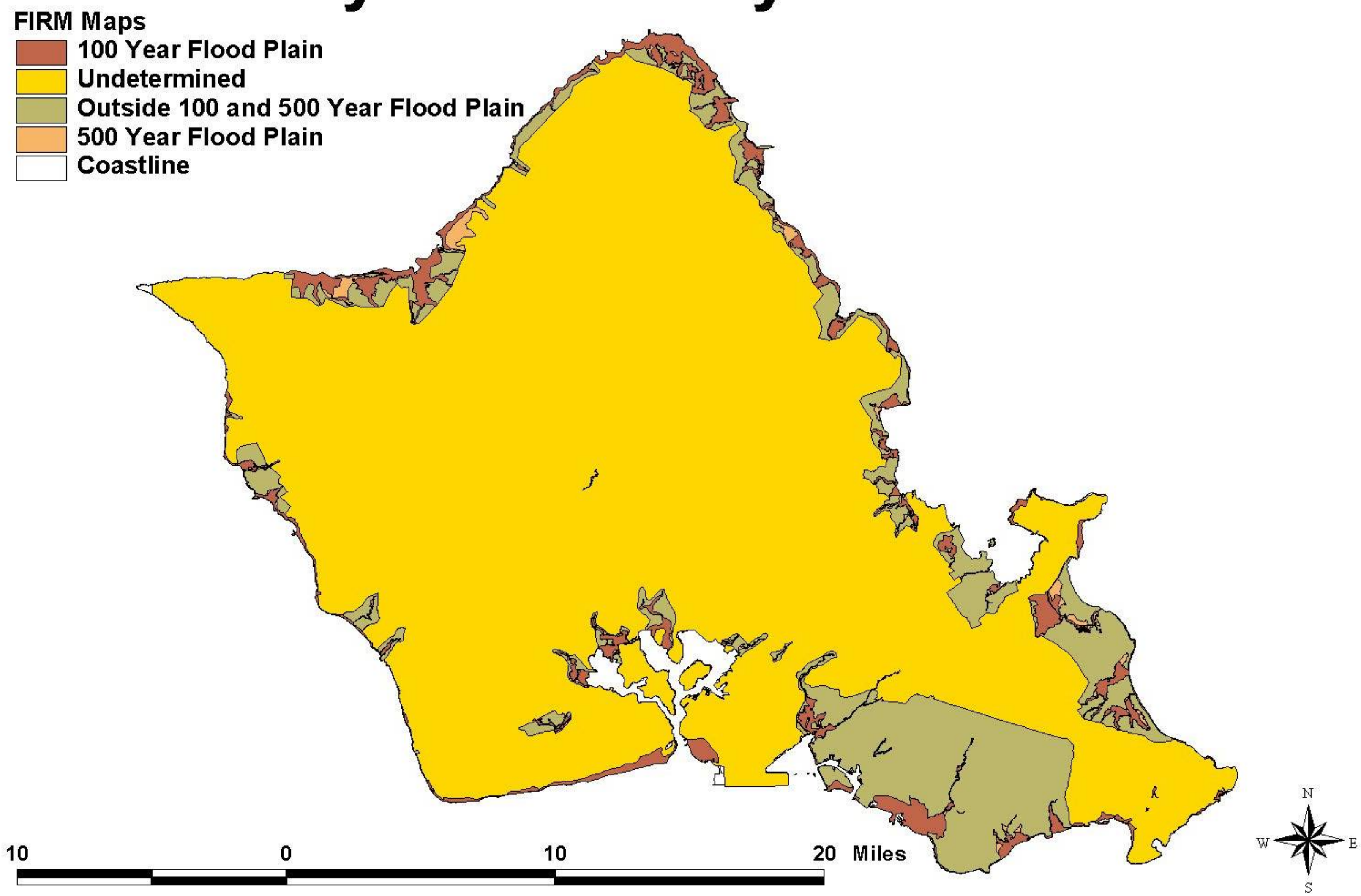
Maps for the County of Hawai'i are available on their website: http://www.hawaii-county.com/maps/maps.html. Maui County is currently updating their website, http://mauigis.net/data/, for publicly served data. General dFIRM information can also be found on FEMA's website, https://hazards.fema.gov/wps/portal/mapviewer.

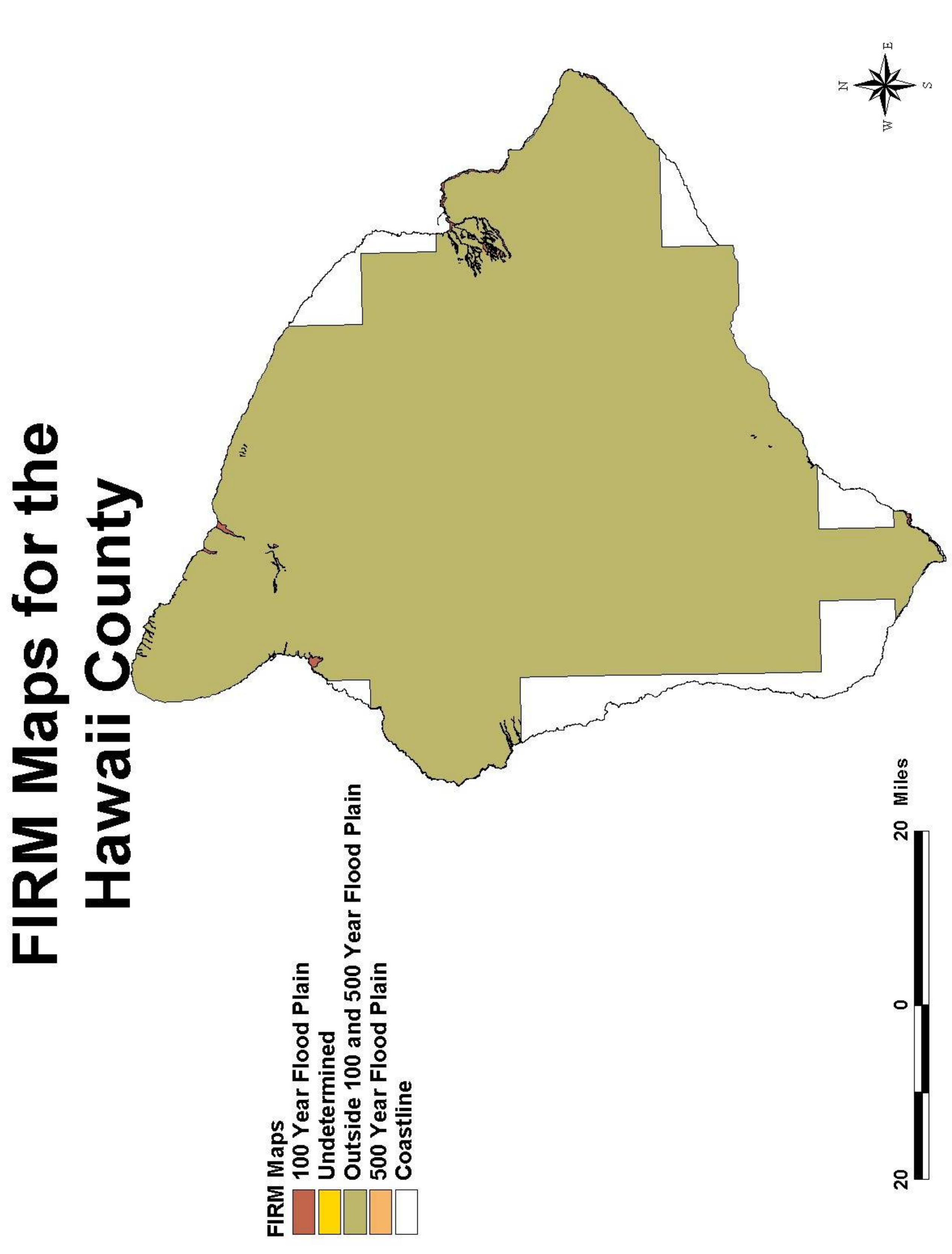
The State DLNR is currently embarking on a Statewide flood hazard assessment tool which will utilize the latest available flood insurance rate map information in a GIS application for residents to use to assist in determining their flood risks. This tool will utilize dFIRMS for Kaua'i County and the City and County of Honolulu, and current FIRMs for Maui and Hawai'i County, and is targeted to be online by the end of 2007.

The four FIRM maps that have been included in the next few pages are based on information in the State GIS Program map layers. The information is not as detailed as the parcel level information held in each county. It does not show the detailed elevation available in the dFIRM maps for the City & County of Honolulu and the County of Kaua'i. For this plan update, these are the best available general maps, but these lose detail at a resolution for the whole County. As the dFIRMs are finalized for the County of Maui and the County of Hawai'i, the maps will be integrated into the State system and will be used in the modeling programs to assess damage risks (described in Chapter 4).

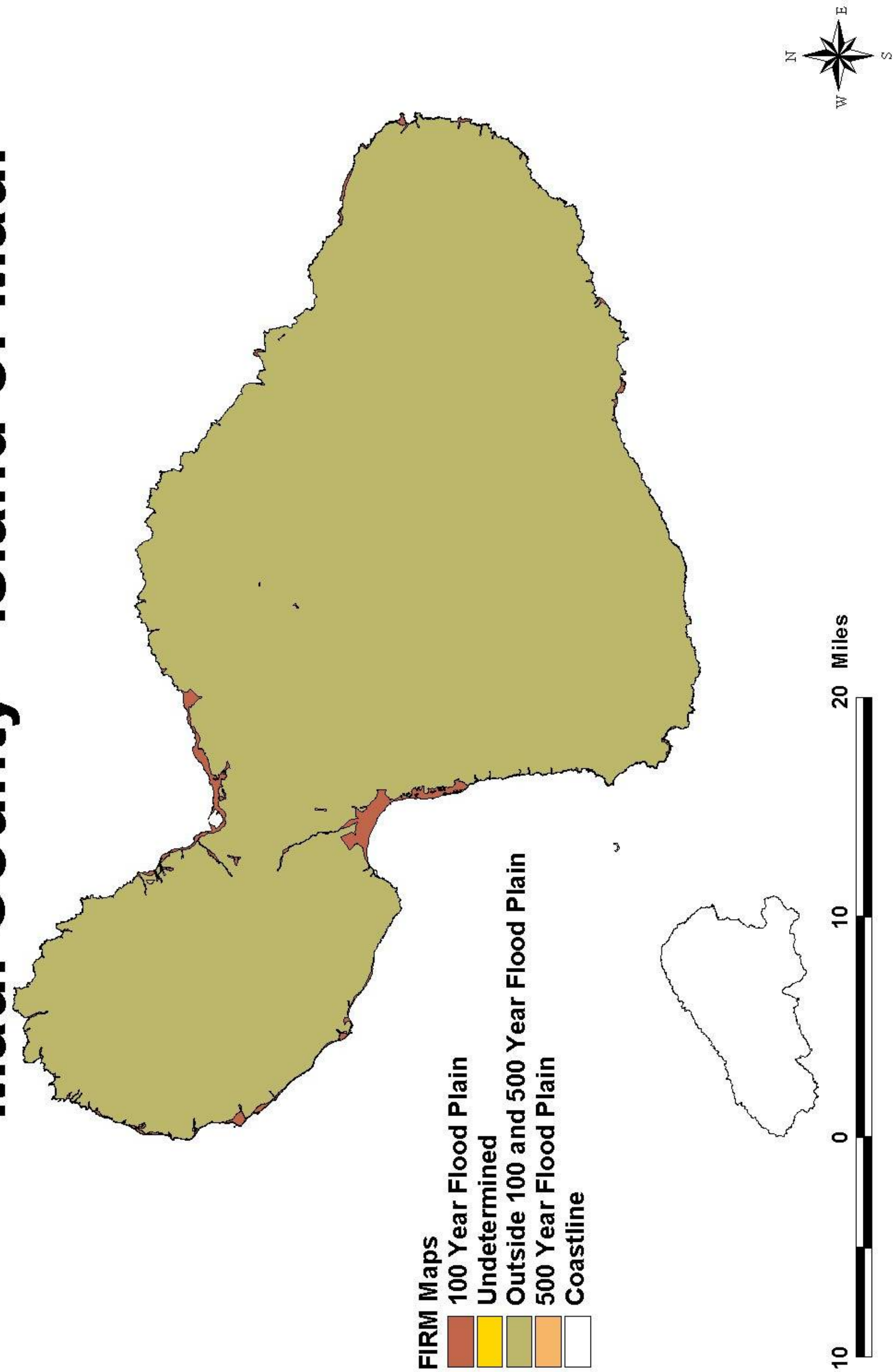

FIRM Maps for the
Kauai County
FIRM Maps
100 Year Flood Plain
Undetermined
Outside 100 and 500 Year Flood Plain
500 Year Flood Plain
Coastline
8
0
8
16 Miles
N
W
E
S

FIRM Maps for the City and County of Honolulu




FIRM Maps for the
Hawaii County
FIRM Maps
100 Year Flood Plain
Undetermined
Outside 100 and 500 Year Flood Plain
500 Year Flood Plain
Coastline
20
0
20 Miles
N
E
S
W

FIRM Maps for the Maui County - Island of Maui



3.2.7 Flood Losses in the State of Hawai‘i

Flooding in Hawai‘i occurs frequently and affects every county. Over time, property damages have been large and many lives have been lost. Increasing development along the scenic coastal areas and shorelines has increased exposure to the risks of flooding and storm surges.

According to the State Department of Land and Natural Resources, floods from tsunami, hurricanes, and rainstorms caused more than 350 deaths, over $82 million in property damage, from 1860 until 1962. There is very little known about flooding events in Hawai‘i prior to 1860. Damage from floods from 1963 through 1982 totals about $395 million. From January 1983 to July 1992, twelve deaths have been attributed to flooding. The 1987 New Years’ caused an estimated $35 million in damages. Floods in March 1991 resulted in damage estimated at $10-$15 million. Also, in December 1991, flood damages amounted to about $7 million.

In November 1996, heavy rains caused extensive damage along the Wai‘anae Coast and in the ‘Ewa Plains that resulted in a Presidential Disaster Declaration, FEMA-1147-DR-HI. Damages were estimated at $11 million.

Another Federal disaster was declared in November 2000 in Hawai‘i County (FEMA-1348-DR-HI). Heavy rains triggered extensive flooding in Hilo and along Highway 11 in the Ka’u District. Damage for this disaster was estimated at $110 million.

The Mānoa Flood Disaster (FEMA-1575-DR-HI) in October 2004 resulted in more than $150 million in damages. There were several smaller flooding events, described in previous tables. The 42-Day Rainfall event in 2006 (major disaster declaration FEMA-1640-DR-HI) resulted in more than $80 million in damages.

As of September 30, 2006, there were 54,309 National Flood Insurance Policies in effect in the State of Hawai‘i. The National Flood Insurance Program has paid a total of $51.7 million claims since 1974 to Hawai‘i’s policyholders. Since 1994, the number and total value of flood insurance policies have more than doubled in Hawai‘i. In December 1994, there were 22,140 flood insurance policies State-wide. In July 1996, the number of policyholders dramatically increased to 47,801 with the value increasing from $2.5 billion to about $5.7 billion. The foregoing makes Hawai‘i the largest per capital participant in the NFIP in the country and third highest in terms of number of policies. Active public education programs by the State and counties contributed to the rise of NFIP coverage in Hawai‘i. Such efforts are on-going.

3.2.8 National Flood Insurance Program

The National Flood Insurance Program (NFIP) provides federally backed flood insurance to property owners in communities that regulate development in floodplains. The United States’ Congress established NFIP to "reduce the loss of life and property and rising cost of disaster due to flooding." The National Flood Insurance Program is a voluntary program based on agreements between federal and local governments. In order to participate, a community must adopt and enforce certain minimum building land use standards designed to reduce property damage from flooding. These regulations, among other things, require new or substantially remodeled structures within special flood hazard areas to be engineered and/or elevated in order to withstand anticipated flood conditions. They also require communities to prohibit development in floodways—areas that allow floodwaters to discharge from special flood hazard areas. NFIP also shifts the cost of flood damage from taxpayers, who ultimately pay for disaster relief, to property owners through flood insurance premiums.

The risk of flood damage to the structure’s lowest floor from a “100 year flood” provides the basis for National Flood Insurance Program premiums. Flood Insurance Rate Maps FIRM) — also based on the "100-year" flood line—delineate special hazard areas and applicable risk premium zones. These Federal Emergency Management Agency generated maps serve as primary reference documents for the National Flood Insurance Program and other flood-related policies and programs at all levels of government.

3.2.9 National Flood Insurance Program Regulations

The Community Development and Regulatory Improvement Act was signed into law in 1994. This Act amended the enabling National Flood Insurance Program (NFIP) legislation in order to reduce federal spending on flood losses and to improve the financial status of NFIP. To this end, it directs federal loan agencies and federally regulated or insured lending institutions to "require flood insurance when making, increasing, extending, or renewing loans and to maintain the coverage for the life of the loan" for all homes in special flood hazard areas. The Act also authorizes: (1) mitigation assistance grants for states and communities to protect homes and businesses; and (2) mitigation insurance for rebuilding to meet improved design and construction standards.

In 1994, new National Flood Insurance Program (NFIP) regulations required all property owners (including those in high-rise condominiums) in "special flood hazard areas" – as determined by the community’s Flood Insurance Rate Map—to insure their properties against flood damage equal to 80% of replacement value. In 2004, an amendment in NFIP rules was approved under Senate Bill 2238, also cited as the ‘‘Bunning-Bereuter-Blumenauer Flood Insurance Reform Act of 2004” (http://www.fema.gov/txt/nfip/fira2004.txt) to address repetitive flood loss that considered an array of amendments and mitigation measures to reduce the costs of the flood program.

Changes in NFIP regulations since 1994 required homeowners in Hawai‘i to buy flood insurance. As a result, the number of Hawai‘i’s NFIP policies more than doubled over an eighteen-month period. In December 1994, there were 21,258 flood insurance policies statewide. By July 1996, the number of policies had increased to 47,801 (Table 3-11), giving Hawai‘i the largest per capita participation in the NFIP in the United States, and third highest number of policies overall. Over the same period, the value of NFIP policies in Hawai'i increased from over $2.5 billion to over $5.7 billion. By 2006, the total policies for the State of Hawaii had increased over 150%, with the most recent statistics showing the total policies at 54,309.

Table 3-13. Flood Insurance Trends in State of Hawai'i, 1993 to 1996 Compared to a Decade Later, 2004-2006 (based on available State Statistics on the National Flood Insurance Program website http://www.fema.gov/business/nfip/statistics/fystats_maps.shtm).

Statewide	*Total Premiums*	*Total Policies*	*Total Claims*	*Total Value of Policies*	*Total Claim Payments*
1993	$7,326,000	17,548		$1,991,737,000	
1994	$9,438,000	21,258		$2,570,035,000	
1995	$12,015,000	44,066		$4,683,245,000	
1996	$12,601,000	47,801		$5,799,690,000	
2004		**48,368**	**102**		**$1,686,582.59**
2005		**50,975**	**73**		**$628,789.61**
2006		**54,309**	**196**		**$3,365,265.30**

Note: Comparative data for premiums, total values, and claim payments were not accessible in NFIP databases for preparation of the table. Archived data could not be accessed to update total claims and current data did not have the costs of premiums listed. The State will take note and look for information to update this error in the next year as the State begins a process for annual updates.

Although the number of policies increased dramatically, the face value of the average National Flood Insurance Program policy remained about the same and the average premium has declined. The mean value of flood policies in Hawai'i increased from $120,897 in December 1994 to $121,332 in July 1996. Over the same period, the average cost of premiums decreased from $443 in 1994, $272 in 1995, and to $264 in 1996. The reductions in the average premiums probably reflect the large number of people outside the special flood hazard area who have purchased policies, as well as the increase in the number of condominium policies. For example, flood insurance costs for one large condo in Honolulu increased from about $9,000 in 1994 to over $39,000 in 1995. This increase was passed directly on to individual homeowners through their maintenance fees.

With flood hazards in recent years, the number of claims as a percentage of total number of policy holders remains low, which indicates that flood mitigation practices in the states have reduced the costs of flood disasters. In looking at the preceding table 3-28, the total amount of claims in 2006, a year of heavy flooding in the State, resulted in less payments than the total premium amount collected a decade earlier in 1996 and the value of the policies also exceeded the total claim payments.

3.2.10 Needs Related to Flood Mitigation

There is an effort is underway through partnerships with county, state and federal agencies and organizations to update the Flood Insurance Rate Maps (FIRMs). With the Federal Emergency Management Agency's Map Modernization Program, there are funds available for updating the maps for different areas. One of the methods considered in this process is using LIDAR data. Each county was asked to prioritize areas that have the greatest need for updated maps. The Map Modernization program began updating maps for Honolulu. The digital FIRM maps have been in use since late 2006. The next update was for the County of Kauaʻi, which has been nearly completed by the end of 2007.

The following table reflects the priority areas for FIRM updates in Kauaʻi County.

Table 3-14. Priority Listing For Updating Of Flood Insurance Rate Maps for County Of Kauaʻi

FLOOD SOURCE	COMMUNITY PANEL NO.	FLOODING PROBLEM	APPROX. STUDY REACH	PRIORITY
Nawiliwili Stream	202C		0.1 Miles	High
Kalaheo Stream	185C		0.7 Miles	High
Kapaa Stream	130D, 135C			High
Wailua River	140D, 130D			High

Panel 202C Approximately 5.79563 Sq. Miles
Panel 185C Approximately 29.37133 Sq. Miles
Panel 140D Approximately 26.47319 Sq. Miles
Panel 130D Approximately 28.74379 Sq. Miles
Panel 135C Approximately 5.21827 Sq. Mile

Table 3-15. Priority Listing For Updating Of Flood Insurance Rate Maps For City and County of Honolulu

FLOOD SOURCE	COMMUNITY PANEL NO.	FLOODING PROBLEM	APPROX. STUDY REACH	PRIORITY
Nuuanu Stream	0354E, 0360E	No 100-year floodplain designated. Continue flood study upstream of limits of previous study	2.3 miles	High
Waolani Stream	0354E	No 100-year floodplain designated. Continue flood study upstream of limits of previous study	0.6 mile	High
Niniko Stream (Tributary of Waolani Stream)	0354E, 0360E	No 100-year floodplain designated. Begin study in the vicinity of Sherman Park and continue upstream.	2.4 miles	High
Heeia Stream & Tributaries	0270E	No 100-year floodplain designated. Continue flood study upstream of limits of previous study	1.06 miles	High
Unnamed Stream (Mokuleia)	0085E	Zone A without floodway and flood fringe areas designated.	2.1 miles	High
Kahawainui Stream	0045E	No 100-year floodplain designated upon completion of flood control project.	Not available	Medium
Wailele and Koloa Streams	0045E	Continue flood study upstream of limits of previous study	1.3 miles	Medium
Waialae Major Drain	0370E	No floodway designated from the ocean outlet to H-1 freeway.	1.0 mile	Medium
Niu Stream	0390E	No detailed study from the ocean outlet to Anolani Street	1.1 miles	Medium
Kuliouou Stream	0390E	No detailed study from the ocean outlet to Kuliouou Road	1.3 miles	Medium
Hahaione Stream	0390E, 0395E	No detailed study from Hawaii Kai Drive to Hahaione Place.	1.3 miles	Medium
Hakipuu Stream	0165E	No 100-year floodplain designated.	1.06 miles	Medium
Waipio Acres Subdivision Flood Control Channels	0226E, 0228E, 0209E	No 100-year floodplain designated.	1.9 miles	Medium
Special Flood Hazard Areas designated Zone A along the shoreline	0315E, 0320E, 0330E, 0335E, 0340E, 0365E, 0370E, 0390E, 0395E	Zone A areas based on possible hurricane inundation. No detailed studies to determine flooding and base flood elevations.	Not available	Medium

Panels 0354E and 0360E Approximately 21.644 Sq. Mi. Panel 0370E Approximately 12.909 Sq. Mi.
Panel 0270E Approximately 15.164 Sq. Mi. Panel 0390E and 0395E Approximately 16.708 Sq. Mi.
Panel 0045E Approximately 8.923 Sq. Mi. Panel 0165E Approximately 15.047 Sq. Mi.
Panel 0226E, 0228E, 0209E Approximately 12.981 Sq. Mi.

Table 3-16. Priority Listing for Updating Of Flood Insurance Rate Maps For Maui County

FLOOD SOURCE	COMMUNITY PANEL NO.	FLOODING PROBLEM	APPROX. STUDY REACH	PRIORITY
Keokea Gulch	0265C	No detailed study	0.8 miles	high
Unnamed Gulch	0265C	No detailed study	1.0 mile	high
Unnamed Gulch 1	0265C	No detailed study	.8 mile	high
Liilioholo Gulch	0265C	No detailed study	1.0 mile	high
Kulanihakoi Gulch	0265C	Unstudied area	1.0 mile	high
Gulch on Piilani Hwy	0265C	Unstudied area	1.6 miles	high
Waipuilani Gulch	0265C	Unstudied area	1.0 mile	high
Waipuilani Gulch	0265C	Unstudied area	1.7 miles	high
Keokea Gulch	0265C	stream diversion	0.8 mile	medium
Unnamed Gulch	0265C	diverted Keokea gulch	0.4 mile	medium
Waipuilani Gulch	0265C	unstudied area	0.6 mile	medium
Waipuilani Gulch Subareas	0265C	unstudied area	1.0 mile	medium
Unnamed Gulch	0265C	unstudied area	0.6 mile	medium
Kamaole Gulch	0265C	100 year storm	0.8 mile	medium
Unnamed Gulch	0265C	higher flood flows	0.8 miles	medium
Unnamed Gulch	0265C	Unstudied area	1.0 mile	medium
Liilioholo Gulch	0265C	Unstudied area	0.8 mile	medium
Mahinahina Gulch	0151C	No detailed study	2.0 miles	high
Kaopala Gulch	0151C	No detailed study	1.8 miles	high
Kahananui Gulch	0151C	Unstudied area	2.0 miles	high
Kahana Stream	0151C	Unstudied area	2.0 miles	high
Kaopala Gulch	0151C	unstudied area	0.3 mile	medium
Olowalu Gulch	0227B	Unstudied area	1.0 mile	high
Launiupoko Gulch	0227B	Unstudied area	1.2 miles	high
Olowalu Stream	0227B	Unstudied area	2.0 miles	high
Papalaua Gulch	0235B	Unstudied area	0.2 mile	high
Makiwa Gulch	0235B	Unstudied area	0.9 mile	high
Ukumehame Gulch	0235B	Unstudied area	1.0 mile	high
Kope Gulch	0160B	Unstudied area	1.0 mile	high
Kalepa Gulch	0160B	Unstudied area	0.7 mile	high
North Waiehu Stream	0160B	Unstudied area	0.70 mile	high
Unnamed Stream south of Waiehu Stream	0160B., 0170B. 0180B	Unstudied area	1.7 miles	high
Iao Stream	0170B	Unstudied area	0.8 mile	high
South Waiehu Stream	0170B	Unstudied area	0.7 mile	high
Waiehu Stream	0170B, 0180B	Unstudied area	0.60 mile	high
Unnamed Gulch	0180B, 0190B	Unstudied area	1.0 mile	high

Table 3-16. Continued

FLOOD SOURCE	COMMUNITY PANEL NO.	FLOODING PROBLEM	APPROX. STUDY REACH	PRIORITY
Hahakea Gulch	0161C, 0153C	Unstudied area	1.2 mile	high
Unnamed Gulch	0161C	Unstudied area	2.8 mile	high
Unnamed Gulch	0153B	Unstudied area	1.0 mile	high
Honokawai Stream	153B	Unstudied area	3.4 miles	high
Kahakuloa Stream	0145B	Flood Zone A	4 miles	High
Unnamed Gulch	0040B	Unstudied area	1.3 miles	medium
Unnamed Gulch	0040B	Unstudied area	0.20 mile	medium
Waiakoa Gulch	0255B	unstudied area	0.8 mile	medium
Waiakoa Gulch	0255B	Unstudied area	1.3 miles	medium
Kauaula Gulch	0163C	Unstudied area	0.8 mile	medium
Lahaina Gulch 2	0163C	unstudied area	1.2 miles	medium
Lahaina Gulch 3	0163C	unstudied area	1.2 miles	medium
Unnamed Gulch	0163C	subject to frequent flooding	0.5 mile	medium
Unnamed Gulch	0138B	unstudied area	4,000miles	medium
Honokena Bay Gulch	0138B	unstudied areea	1.0 mile	medium

Table 3-17. Priority Listing for Updating Of Flood Insurance Rate Maps For Hawai'i County.

FLOOD SOURCE	COMMUNITY PANEL NO.	FLOODING PROBLEM	APPROX. STUDY REACH	PRIORITY
Waimea:Puukapu	167C, 168E,			Low
Waiaka	162C, 164D			Low
Kona	926E, 927D			Medium
Hilo	860C, 870C, 880C, 890C			Medium
Puna	1125C, 1150C			High
Waikoloa	283C			High

3.2.11 Flood Map Modernization Efforts

With priorities in place, there are efforts underway to improve accuracy and update the flood insurance rate maps. Under the Map Modernization Program, the Federal Emergency Management Agency (FEMA) initiated two projects in the State of Hawai'i. The areas that will be remapped are: 1) Waimea-Pu'ukapu on the Island of Hawai'i and; 2) Kihei on the Island of Maui. These areas were determined to be priorities because the maps were outdated and did not reflect the current situation with increases in human settlement. To meet FEMA's new guidelines for Digital Flood Insurance Rate Maps (dFIRM), technology such as Light Detection and Ranging or LIDAR will be utilized to capture more accurate elevation data to create a digital elevation model (DEM) to be used in the hydrologic/hydraulic analysis. Other products such as orthoimagery will also be incorporated within the final mapping product. This is being conducted in an effort to meet FEMA's guidelines of creating a digital product that can be utilized in Geographic Information Systems (GIS). The specifications can be found at: http://www.fema.gov/pdf/fhm/frm_gsal.pdf.

The State of Hawaiʻi Geographic Information Systems Program was awarded a grant from the National Oceanic and Atmospheric Administration to collect and process LIDAR elevation data for the entire Island of Oʻahu and Lahaina on the Island of Maui. Although this effort was funded for different reasons other than flood mapping, the data will be captured and processed to meet FEMA's standards, such that it can be used for the Flood Map Modernization Program. In conjunction with the LIDAR, the National Geospatial-Intelligence Agency (NGA) has determined that Honolulu is one of the most critical cities under homeland security and has requested orthoimagery be taken as the LIDAR flights are being conducted.

The City & County of Honolulu had their dFIRMs on September 30, 2004 with corrections by the end of June 2005. Kauaʻi County had their maps September 16, 2005. The funding for this effort has been available in phases. There is currently ongoing effort to update the Maui and Hawaiʻi imagery and maps. Because of frequent cloud cover, the satellites have had some difficulty in acquiring necessary imagery for Hawaiʻi County. FEMA is using QuickBird satellite imagery for the entire assessment of Maui, but will need to leverage funding to complete some of the missing imagery in Hawaiʻi County. The dFIRMs improves the ability of the state and counties to analyze risks related to the assets described in Chapter 4 to determine risk and vulnerability assessments.

Even so, the dFIRMs represent the digital mapping of previously developed FIRM maps. The data and studies that inform the maps still need to be updated with digital elevation, satellite imagery, and analyses of historical flooding events to determine better maps with which to make decisions.

3.3 Drought

A drought is a period of abnormally dry weather. Drought diminishes natural stream flow and depletes soil moisture, which can cause social, environmental and economic impacts. In general, the term "drought" should be reserved for periods of moisture deficiency that are relatively extensive in both space and time.

A drought is caused by a deficiency of rainfall and can be exacerbated by other factors including high temperatures, high winds, and low relative humidity. Hydrological drought can also result from anthropogenic activities that place water demand at unsustainable levels and ultimately strain groundwater supplies. Anthropogenic strain is due to burgeoning populations, irrigation, and an uneven diffusion of conservation practices in both the public and private sector. Thus, the severity of the drought depends not only on the duration, intensity, and geographic range, but also on the regional water supply demands made by human activities and vegetation.

The significance of the recorded drought history for the State results less from tracking the intermittence of drought event occurrence than that it is a testament to the sectoral nature of drought impacts. As shown in the following table, drought impacts have been historically construed primarily in agricultural terms. However, it is important to note how drought analysis has evolved and the current need for a multi-sectoral analysis.

3.3.1 Historical Drought Events

Table 3-18. Drought Events and Impacts, 1901-2007.

Year	Area	Remarks
1901	North Hawai‘i	Severe drought, destructive forest fires.
1905	Kona, Hawai‘i	Serious drought and forest fires.
1908	Hawai‘i and Maui	Serious drought.
1912	Kohala, Hawai‘i	Serious drought and severe sugarcane crop damage for two years.
1952	Kaua‘i	Long, severe dry spell.
1953	Hawai‘i, Kaua‘i, Maui and O‘ahu	Water rationing on Maui; Water tanks in Kona almost empty; 867 head of cattle died; Pineapple production on Molokai reduced by 30 percent; Rainfall in the islands had been 40 percent less than normal.
1962	Hawai‘i and Maui	State declared disaster for these islands; Crop damage, cattle deaths, and sever fire hazards; Losses totaled $200,000.
1965	Hawai‘i	State water emergency declared; Losses totaled $400,000.

1971	Hawai‘i and Maui	Irrigation and domestic water users sharply curtailed.
1975	Kaua‘i and Oahu	Worst drought for sugar plantations in 15 years.
1977 – 1978	Hawai‘i and Maui	Declared State disaster for these islands.
1980-81	Hawai‘i and Maui	State declared disaster; Heavy agricultural and cattle losses; Damages totaling at least $1.4 million.
1983 – 1985	Hawai‘i	El Niño effect; State declared disaster; Crop production reduced by 80 percent in Waimea and Kamuela areas; $96,000 spent for drought relief projects.
1996	Hawai‘i, Maui, and Moloka‘i	Declared drought emergency; heavy damages to agriculture and cattle industries; Losses totaling at least $9.4 million.
1998 – 1999	Hawai‘i and Maui	State declared drought emergency for Maui; County declared emergency for Hawaii due to water shortages; heavy damages to agriculture and cattle industries; Statewide cattle losses alone estimated at $6.5 million.
2000 – 2002	Hawai‘i, Maui, Moloka‘i, O‘ahu, Kaua‘i	Counties declare drought emergencies; Governor proclaims statewide drought emergency (2000); Secretary of the US Department of Interior designates all Counties as primary disaster areas due to drought (2001); East Maui streams at record low levels; Statewide cattle losses alone projected at $9 million.
2003-2004	Hawai‘i, Maui, Moloka‘i, O‘ahu, Kaua‘i	Governor proclaims statewide drought emergency (2003); County of Hawaii Mayor issues drought emergency proclamation (2003); Secretary of the U.S. Department of the Interior designates all counties as a primary disaster area due to drought (2004).
2007	Hawai‘i, Maui, Moloka‘i, O‘ahu, Kaua‘i	Counties experience drought emergencies and wildfires associated with drought. County of Hawai‘i Mayor issues drought emergency proclamation (2007); County of Maui Department of Water Supply places 10% mandatory water conservation on Upcountry customers.

Source: Hawaii Drought Monitor, Commission on Water Resource Management.

As illustrated in the table, droughts have been and will continue to be a significant concern in the State of Hawai‘i. Planning for and coping with recurring, if unpredictable, drought events is complicated by the inherent water resource limitations of our islands and the uneven range of drought related concerns and relevant priorities across counties. The statewide variability in resources, vulnerability, and risk necessitates a sectoral approach to drought mitigation. Statewide, three sectors were identified as being vulnerable to drought as well as having the potential to be ameliorated through mitigative measures: public water supply; agriculture and commerce; and environment, public health and safety. The Hawai‘i Drought Plan further asserts that these three drought impact sectors are critical to the health and welfare of Hawaii’s people in terms of the social, economic and environmental arenas.

The Water Supply Sector encompasses public/private urban and rural drinking water systems, agriculture water systems, and other water networks. Due to the fact that fresh water is crucial to human survival in a variety of direct and indirect ways, one of the most important indirect aspects being maintaining a viable agriculture and commerce sector, minimizing the impact of drought to Hawaii's drinking water supply and other fresh water supplies is very important.

During drought periods, the agriculture and commerce sector is severely negatively impacted due to strain born of dependence on both surface water and rainfall. Rainfall shortage induced impacts are often exacerbated by the limits placed on groundwater pumping during drought periods. A persistent rainfall shortage and resultant lack of soil moisture can result in reduced ground cover and agricultural crop yields. Reduced ground cover places stresses and strains on livestock herd sizes, and is also associated with increased incidence of erosion. Environment, Public Health, and Safety for this project focuses solely on wildfire occurrence. Drought conditions heighten the potential incidence, extent and rapidity of the spread of wildfire. Wildland fires not only endanger human lives at the urban/wildland interfaces, but also endanger species of flora and fauna, which already may be especially susceptible due to drought conditions

A risk assessment of these sectors should inform clear and concise mitigation measures to be undertaken during drought and non-drought periods. Pursuant to this goal a drought frequency analysis based on the Standardized Precipitation Index method was performed for all four counties in the State of Hawaiʻi, which graphically represents the spatial distribution of drought occurrences. Statewide drought frequency and sector based Geographic Information System (GIS) mapping were then integrated to identify risk areas for each county. For this analysis drought risk is considered a product of drought frequency and location specific vulnerability.

The drought frequency analysis was conducted for three drought stages (moderate, severe, and extreme) and for different drought durations (e.g., 3-month, 12-month). Throughout the various permutations of county, severity, and duration several patterns emerged. For example, a common risk area across all three sectors and three drought stages in the County of Hawaiʻi is found on the western side of the island near Kona. For Maui County, the common risk area to the water supply and environmental sectors is within the Kula region. For the City and County of Honolulu, central Oʻahu appears to be the common risk area across all the sectors for two drought stages. For Kauaʻi County, a small belt in the southeastern corner appears to be more vulnerable to some sectors and drought levels. An in-depth discussion of the findings can be found in the *Drought Risk and Vulnerability Assessment and GIS Mapping Project*. However, a brief discussion of sector specific trends by county follows.

3.3.2 Water Supply Sector

The Water Supply Sector for the County of Hawaiʻi was particularly illustrative of the need for drought mitigation as identified through our analysis. Over 50 percent of the Island of Hawaiʻi is classified in the lowest rainfall tercile, and when coupled with the uneven spatial extent of service coverage in populated areas along the Kona Coast and in Pahoa, clear vulnerability exists. Other locations on the Island of Hawai‘i that fit the vulnerability criteria are areas in South Kohala and South Kona.

Within Maui County the only area that satisfies all our criteria for high vulnerability within the water supply sector are on the island of Lanai. It should be noted that greater than 50 percent of both Maui and Moloka‘i are in the low tercile of median annual rainfall, and that these areas have the largest density of population within those respective islands, hence increasing the vulnerability of the those areas to persistent hydrological drought despite adequate public water supply system coverage.

The City and County of Honolulu has the most extensive public water supply system. According to the Honolulu Board of Water Supply, approximately 92 percent of O‘ahu’s water comes from groundwater. The integrated municipal water system and its inherent flexibility allow the Board to pump water from one district to another, particularly during emergencies, thus drastically reducing vulnerability.

As for Kaua‘i County, all the heavily populated areas fall within the approximately 75% of the island in the lowest rainfall tercile. These areas are all serviced by the public water supply system, and thus it can be inferred that these populations are not as susceptible to meteorological drought, but are susceptible to hydrological drought that depletes groundwater.

3.3.4 Agriculture and Commerce Sector

The agriculture and commerce sector for Hawai‘i County is indicative of the statewide pattern of agriculture and ranching situated in low rainfall areas. The bulk of the extensive and intensive agriculture including along the Kona Coast, Lower and Upper Kohala region, and South Point, Ka‘u District all receive relatively low rainfall. It is assumed that a greater proportion of the extensive agriculture lands is solely dependent on rainfall for moisture, as opposed to irrigation, and is thus even more vulnerable than intensive agriculture.

Based on this analysis, Maui County’s agriculture sector is also highly vulnerable with over 75 percent of its extensive and intensive agriculture lands falling within low rainfall areas. Areas on the island of Maui that are vulnerable are typically on the western end of the island, areas like Makawao, Kula, Lahaina, ‘Ulupalakua, and Kapalua. The islands of Moloka‘i and Lāna‘i are just as vulnerable within the agriculture and commerce sector. Excluding areas along the eastern and southeastern slopes of the Moloka‘i Forest Reserve, all of the Moloka‘i and Lāna‘i lands in intensive and extensive agriculture are also very vulnerable to meteorological drought.

The City and County of Honolulu, has the fewest acreage still dedicated to the agricultural industry, both in terms of intensive and extensive agriculture. However, even these relatively small parcels are vulnerable to meteorological drought as the upper ‘Ewa Plains of Kunia and the areas from Helemano to Haleiwa receive low rainfall.

Kauaʻi County is mostly affected by meteorological drought in the agriculture lands along the southern and northwestern parts of the island. The majority of the agriculture services are in the intensive category located along the coastal areas in the south from Lāwaʻi to Mānā. All of these lands are in the lowest rainfall tercile.

3.3.5 Key Elements in Drought Planning for Hawaiʻi

The goal of the Hawaiʻi Drought Plan was to develop coordinated emergency response mechanisms, while at the same time outlining steps towards mitigating the effects of future drought occurrences. The key elements were outlined as follows:

- A comprehensive rainfall pattern and climate monitoring system to provide early warning of emerging droughts to decision makers, stakeholders, and the general public.
- A network of people and/or organizations who can effectively assess evolving impacts of water shortages on agriculture, recreation, hydropower, municipal and domestic water supplies, wildlife, and other areas that are sensitive to reduced rainfall and fluctuations in water supply.
- Clear policies and establishment of response entities to implement immediate and short-term response measures to reduce drought impacts and longer-term mitigation measures to reduce the future impacts of drought.

In addition, the drought plan makes several recommendations regarding performance of risk management assessments pertaining to potential drought impacts.

3.4 Wildfires

Normally considered a natural hazard in its own right, for the sake of this risk and vulnerability analysis, wildfire was subsumed under drought as representative of the public health and safety impact sector. Drought is one of many factors contributing to the complexity of forest ecosystems adapted to frequent fires. Although drought increases the potential for catastrophic wildfire, drought cannot be singled out as the sole cause or key determinant in wildfires. Other factors include wildland fuels accumulated during many decades of unwise fire suppression, overcrowded tree stands, down trees during heavy winds and storms, and the overgrowth of brushes and grasses mixing with urban fuels at the wildland-urban interface. A more appropriate way of characterizing the relationship is that wildland fires tend to be induced by drought rather than being caused by them.

This sector is linked directly to the issues surrounding wildland-urban interface. The wildland-urban interface is an area where human settlements such as homes, ranches, and farms adjoin areas considered wildlands. Urban expansion has driven both the increases in incidence and extent of the wildland-urban interface areas. A key assumption, specifically for this analysis, was that Census Designated Places (CDP) represents communities at this wildland interface, and hence should be considered “Communities at Risk.” The National Fire Plan developed the term “Communities at Risk” to represent precisely such communities that are at the wildland-urban interface and are at risk from wildland fires. Summary Table 3-33 lists “Communities at Risk” statewide.

The main assumption used in this analysis was that wildland fires tend to occur in the same places time and time again. The crux of the analysis for this sector was that proximity of past wildland fires to the Census Designated Places (CDP) or “Communities at Risk” will provide some indication of how vulnerable a community may be, based on the assumption that wildfires tend to reoccur in the same areas. To tackle this problem, paper maps of wildfires over the past 20 years were gathered and converted to a GIS format so that they could be overlaid on to the “Communities at Risk” layers. In addition, a major roads layer was also included given that roads have multiple functions in relation to wildfire; access by firefighting crews, man–made fire breaks, and in some cases wildfire expansion corridors. Overlaying median annual rainfall terciles of High, Medium, and Low, provided further clarification of vulnerability. Communities that are both low rainfall and in close proximity to past wildland fires would be considered most vulnerable to future wildland fires. Other reference layer information served to flesh out vulnerability and potential burn patterns. For example, wildfires that span multiple land uses, which can be inferred as having different ground cover, tend to be associated with different burn patterns or burn characteristics.

Table 3-19. Communities at Risk in the Vicinity of Federal Lands.

Communities at Risk	Information
Aiea, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Aliamanu-Salt Lake, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Ewa, HI	
Fern Acres, HI	
Fern Forest, HI	
Glenwood, HI	
Hawaii Kai, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Kailua-Kona, HI	
Kaneohe, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Kapoho, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Kaupo, HI	
Kawaihae, HI	
Kekaha, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Kilauea, HI	
Kipahulu, HI	
Kokee, HI1	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Koolauloa, HI	
Makakilo Mauka, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Makakilo/Kapolei, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Mililani Mauka, HI	
Mililani-Waipio, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Moanalua, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Mokapu, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
North Shore, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Pearl City, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Volcano, HI	
Wahiawa, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Waianae Coast, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Waimanalo, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior
Waipahu, HI	In the vicinity of Federal lands other than those managed by the Departments of Agriculture and the Interior

3.4.1 Fires Related to Environment, Public Health, and Safety

Due to the fact that the bulk of our analysis relies on wildfire burn history and spatial extent, clear patterns emerged in the wildfire prone Hawaiʻi County with approximately 48 fires burning a total of 90,159.19 acres with which to draw inference. Twenty-nine out of the 48 total fires were on the western end of the island, in the proximity of the Waikoloa Village "Community at Risk." Although other "Communities at Risk" have greater populations, since vulnerability in this analysis is primarily a function of proximity, Waikoloa's vulnerability is considered greater than the other "Communities at Risk" locations. When combining the past burn areas layer and the rainfall tercile layer, it is apparent that "low rainfall" zones increase the odds of wildfire occurrence. A total of 40 of the 48 fires in Hawaiʻi County from 1953 to 2001 occurred in "low rainfall" zones. Also, due to the infrequency of lightning strike induced fires, and since most of the wildfires occurred in either agriculture or conservation land use zones, it may be assumed that a greater proportion of these fires was started by human negligence or arson, rather than by natural means. Although not broken down by county, the following table illustrates the range of potential wildfire triggers, as well as substantiates our general assertion that human negligence is the primary trigger.

Table 3-20. Wildland Fire Causes, Incidence, and Extent of Damage in Acres, 1994-2002.

Year	Lightning		Campfire		Smoking		Debris burning		Arson	
	Number	Acres	Number	Acres	Number	Acres	Number	Acres	Number	Acres
1994	0.0	0.0	1.0	0.3	9.0	4.0	18.0	9.5	43.0	366.3
1995	0.0	0.0	7.0	3.9	29.0	440.8	14.0	2853.0	58.0	616.0
1996	2.0	2.2	12.0	6.1	14.0	18.3	18.0	37.4	21.0	106.1
1997	2.0	4.1	4.0	1.4	9.0	6.6	8.0	4.9	5.0	117.6
1998	0.0	0.0	9.0	0.9	16.0	2258.7	28.0	81.6	49.0	3291.5
1999	1.0	20.0	3.0	1.6	5.0	83.7	14.0	290.9	25.0	14173.9
2000	1.0	2.0	3.0	0.3	13.0	9.7	22.0	241.7	18.0	74.1
2001	0.0	0.0	8.0	6.3	13.0	16.3	7.0	17.7	13.0	117.6
2002	1.0	0.1	9.0	0.8	13.0	28.7	23.0	9.0	16.0	139.4
Total	7.0	28.4	56.0	21.6	121.0	2866.8	152.0	3545.7	248.0	19002.5

Year	Equipment		Railroads		Children		Miscellaneous	
	Number	Acres	Number	Acres	Number	Acres	Number	Acres
1994	3.0	14.1	0.0	0.0	2.0	0.4	48.0	19798.8
1995	14.0	1446.3	0.0	0.0	13.0	1213.5	82.0	2994.8
1996	13.0	109.7	0.0	0.0	9.0	3.1	41.0	183.8
1997	13.0	30.7	0.0	0.0	7.0	3.6	19.0	208.2
1998	16.0	847.8	0.0	0.0	11.0	2473.7	76.0	28360.6
1999	8.0	572.3	0.0	0.0	4.0	7.4	72.0	5226.0
2000	11.0	2197.6	0.0	0.0	13.0	12.7	44.0	393.2
2001	5.0	61.5	0.0	0.0	3.0	11.6	59.0	849.3
2002	7.0	0.7	0.0	0.0	5.0	1.8	117.0	2202.9
Total	90.0	5280.7	0.0	0.0	67.0	3727.8	558.0	60217.6

Source: State of Hawaii, Department of Land and Natural Resources, Division of Forestry and Wildlife.

Over a period from 1980 to 2002, Maui County had a total of 42 fires, burning over 30,000 acres of land. Over this period, the Kaunakakai “Community at Risk” on the island of Molokaʻi has had 15 wildland fires, 5 in 1998 alone, consuming a total of 13618.52 acres of land. Over on the island of Maui, the Waikapu “Community at Risk” had 11 wildland fires from 1980 to 2002, with 6 in 1991 alone. These fires consumed a total of 8,483.85 acres. A greater proportion of these wildland fires occurred in precipitation zones that have been designated as “low rainfall”, hence further strengthening the association or correlation of wildfire and low rainfall. Examination of the analysis results show that within Maui County, not only are the fires located in “low rainfall” zones, but the greater proportion on the wildland fires are occurring within proximity of populated areas and not in remote locations. Again, the interpretation is that a greater proportion of these fires were started by human negligence or arson, rather than by natural means.

The City and County of Honolulu, from 1998 to 2002, according to the map data had 9 fires, 5 of which were located in the Waipiʻo “Community at Risk”. Four of the fires occurred in 2002 alone, and were fires that were between communities, hence endangering more than one community. The City and County of Honolulu, has the largest number of “Communities at Risk,” primarily due to the fact that 72 percent of the state’s population lives in the City and County of Honolulu, and there is a larger mix of urban/rural land to open land, with approximately 35 percent urban/rural, as compared to Maui County (5%), Kauaʻi County (5%), and Hawaiʻi County (2%). This can be interpreted as a density factor or a built-up area to open land ratio, which can be very dangerous during a wildland fire. Most of the wildland fires in the City and County of Honolulu have taken place on the central to western end of the island, either in “low rainfall” locations or between zones of low to medium rainfall within agriculture lands. Some areas, like the Waipio location mentioned previously, abut communities along major road corridors. Unlike other counties, there was a higher incidence of what appeared to be “natural” wildfires, such as Waiʻanae Valley and Kaʻena Point.

Kauaʻi County has had the smallest wildfire incidence despite intermittent drought conditions. Although Kauaʻi is known for its relatively wet weather most of the “high rainfall” locations are situated high in the central mountains on conservation land. Much of the “medium rainfall” zones are likewise located in the central area of the island, in remote mountainous areas. As such, a greater portion of the island falls within the “low rainfall” category. The wildfires that have been mapped have actually occurred in conservation or agriculture land, with the distances to “community at risk” ranging from 1.3 miles away to distances of 16.2 miles away. Hence, from this analysis, wildland fires may not appear to be much of a problem on Kauaʻi, but as stated previously, wildland fire vulnerability is not predictive of wildfire occurrence. The following table summarizes all wildfire events statewide and the spatial relationship between wildfire events and relevant CDPs.

Table 3-21. Historic Wildfire Events by County and Impacted CDPs.

County	Year	No.	Total Acreage	Closest CDP	Distance	CDP Pop (Yr 2000)
Hawaii	1953	1	3,681.34	Waimea	10.4 Miles	7,208
	1969	1	2,616.55	Waikoloa Village	3.02 Miles	4,806
	1972	1	8.966	Waimea	5.76 Miles	7,208
	1973	8	7,223.44	Waikoloa Village	4.46 Miles	4,806
	1975	2	342.209	Waimea	11.19 Miles	7,208
	1976	2	5.047	Honalo	12.82 Miles	1,987
	1977	2	1,065.11	Waimea	11.05 Miles	7,208
	1978	1	35.42	Waikoloa Village	11.67 Miles	4,806
	1983	1	5.82	Waikoloa Village	5.10 Miles	4,806
	1985	1	24,270.08	Waikoloa Village	3.28 Miles	4,806
	1987	3	11,701.20	Waikoloa Village	0 Miles	4,806
	1988	1	575.452	Kalaoa	6.15 Miles	6,794
	1989	1	3,318.15	Puako	2.14 Miles	429
	1991	2	215.831	Kalaoa	6.28 Miles	6,794
	1993	4	1,451.91	Waikoloa Village	6.14 Miles	4,806
	1994	2	714.632	Honalo	12.42 Miles	1,987
	1995	3	1,408.47	Kailua	2.88 Miles	9,870
	1996	1	72.988	Waikoloa Village	6.23 Miles	4,806
	1998	5	12,666.38	Waikoloa Village	0.84 Miles	4,806
	1999	4	18,709.09	Waikoloa Village	0.38 Miles	4,806
	2001	2	71.106	Kailua	14.22 Miles	9,870
Maui	1980	4	4,829.06	Kualapuu	0 Miles	1,936
	1984	5	2,003.21	Kihei	0.85 Miles	16,749
	1985	1	0.269	Wailea-Makena	4.11 Miles	5,761
	1987	4	970.061	Kaunakakai	2.33 Miles	2,726
	1988	2	83.581	Waikapu	0.48 Miles	1,115
	1989	2	31.264	Waikapu	0.39 Miles	1,115
	1990	4	207.659	Lanai City	1.34 Miles	3,164
	1991	6	8,320.79	Waikapu	2.55 Miles	1,115
	1992	3	315.761	Kaunakakai	1.45 Miles	2,726
	1993	3	217.51	Kaunakakai	2.00 Miles	2,726
	1995	1	48.217	Waikapu	1.87 Miles	1,115
	1998	5	12,145.19	Kaunakakai	0 Miles	2,726
	2001	1	547.524	Lahaina	2.27 Miles	9,118
	2002	1	296.384	Lahaina	3.45 Miles	9,118
Kauai	1998	1	1.328	Waimea	5.00 Miles	1,787
	1999	2	16.167	Waimea	6.85 Miles	1,787
	2000	2	12.001	Hanalei	10.44 Miles	478
Honolulu	1998	4	864.808	Mokuleia	1.08 Miles	1,839
	2000	1	272.969	Waipio	0 Miles	11,672
	2002	4	2,765.25	Pearl City, Waipio	0 Miles	30,976/11,672

Source: Department of Land and Natural Resources, Commission on Water Resource Management, Drought Risk and Vulnerability

The following tables update annual reports of wildfires for the years, 2004- 2006. These tables and information are available on the Department of Land and Natural Resources Division of Forestry and Wildlife Fire Management Program website (http://www.state.hi.us/dlnr/dofaw/fmp/firedata.htm).

Annual Wildfire Summary Report
Calendar Year: 2004
Total Acres Protected: 3,360,000

Acres Burned By Cause:

Cause	No.	Acres
Lightning	2	2
Campfire	7	8.4
Smoking	5	70.4
Debris burning	4	12.7
Arson	16	48.6
Equipment	9	16.5
Railroads	0	0
Children	1	0.1
Miscellaneous	39	1910.6
TOTAL:	89	2069.3

Acres burned by Size Class:

Size Class	No.	Acres
Class A - 0.25 acres or less	37	4.1
Class B - 0.26 to 9 acres	39	63.2
Class C - 10 to 99 acres	5	152
Class D - 100 to 299 acres	0	0
Class E - 300 to 999 acres	1	350
Class F - 1000 to 4999 acres	1	1500
Class G - 5000 acres or more:	0	0
TOTAL	83	2069.3

Annual Wildfire Summary Report
Calendar Year: 2005
Total Acres Protected: 3,360,000

Acres Burned By Cause:

Cause	No.	Acres
Lightning	3	4.1
Campfire	8	801.7
Smoking	0	0
Debris burning	5	1.6
Arson	12	218.2

Equipment	6	135.9
Railroads	0	0
Children	0	0
Miscellaneous	75	25331.1
TOTAL:	109	26492.6

Acres burned by Size Class:

Size Class	**No.**	**Acres**
Class A - 0.25 acres or less	42	5.2
Class B - 0.26 to 9 acres	43	92.4
Class C - 10 to 99 acres	13	245
Class D - 100 to 299 acres	4	550
Class E - 300 to 999 acres	2	1200
Class F - 1000 to 4999 acres	4	9500
Class G - 5000 acres or more**:**	1	14900
TOTAL	109	26492.6

Annual Wildfire Summary Report
Calendar Year: 2006
Total Acres Protected: 3,360,000

Acres Burned By Cause:

Cause	**No.**	**Acres**
Lightning	7	3596.3
Campfire	4	783.1
Smoking	0	0
Debris burning	12	37.9
Arson	27	3104.3
Equipment	15	679.9
Railroads	0	0
Children	0	0
Miscellaneous	140	6383.3
TOTAL:	205	14584.8

Acres burned by Size Class:

Size Class	**No.**	**Acres**
Class A - 0.25 acres or less	100	14.2
Class B - 0.26 to 9 acres	67	114.6
Class C - 10 to 99 acres	23	550
Class D - 100 to 299 acres	2	300
Class E - 300 to 999 acres	10	5793
Class F - 1000 to 4999 acres	3	7812
Class G - 5000 acres or more**:**	0	0
TOTAL	205	14584.8

3.5 Climate Variability and Change

This section on climate variability and change has been incorporated as a separate section of the plan beginning with the 2007 Plan Update. Climate Variability and Climate Change are not categorized as "hazards," as the other hazards included in this chapter. Nonetheless, the release of the Intergovernmental Panel on Climate Change (IPCC) scientific assessment reports in early 2007 and the growing public awareness on the issue of climate change because of dramatic reports of melting icecaps and glaciers have drawn international public attention to issues that can cause significant changes in climate that precipitate disaster.

Climate risks in near and long term will have significant impacts on the Hawaiian Islands, in terms of changes to ecosystems and geography. Development choices in combination with these changes will have significant consequences with the impacts of hazard events. The four previously discussed disasters were climate-related disasters and there are correlations with these events and climate variability. One reason that this section is separated is to avoid confusion in causality, as the hazards have occurred independently of correlation with periods of climate variability. Global warming, or climate change, definitely has impacts on changes in climate that can lead to increased disaster occurrence, but hurricanes, floods, droughts, and wildfires may be related to seasonal and interannual climate variation.

In order to address a range climate risks for Hawai'i in this mitigation plan, the plan developers and the Forum members decided to incorporate the discussion of climate variability and change into a separate section. For this chapter, the inclusion of this section enables the State to think about the characteristics and science of the climate system, and to think about the full range of impacts. Coastal shorelines and ecosystems are at risk from climate change, which may have significant impacts in the impacts of geological hazards such as erosion, landslides, and sea level rise. New seismic theories discuss the relationship that sea level rise can have on building pressure in the earth to produce certain types of earthquakes. Therefore, there should be a basic understanding of the characteristics of climate variability and change to better inform risk management decisions discussed in later chapters.

3.5.1 Climate Variability:El Niño-Southern Oscillation and La Niña

Climate variability refers to relatively short-term variations in the natural climate system. The climate variations often show in seasonal and interannual climate in periods that deviate significantly from the "normal" climate, such as the patterns associated with the El Niño-Southern Oscillation (ENSO) cycle (both El Niño and La Niña) or the Pacific Decadal Oscillation (PDO). Numerous resources are available in explaining the phenomena of El Niño-Southern Oscillation, which has significant impacts for island climatologies.

There are a wealth of materials created to provide a concise understanding of climate variability. the explanations have been copied directly following from the NOAA Pacific

Marine Environmental Lab website: http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html.

3.5.1.1 Understanding El Niño

El Niño is an oscillation of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe. Among these consequences are increased rainfall across the southern tier of the US and in Peru, which has caused destructive flooding, and drought in the West Pacific, sometimes associated with devastating brush fires in Australia. Observations of conditions in the tropical Pacific are considered essential for the prediction of short term (a few months to 1 year) climate variations. To provide necessary data, NOAA operates a network of buoys which measure temperature, currents and winds in the equatorial band. These buoys daily transmit data which are available to researchers and forecasters around the world in real time.

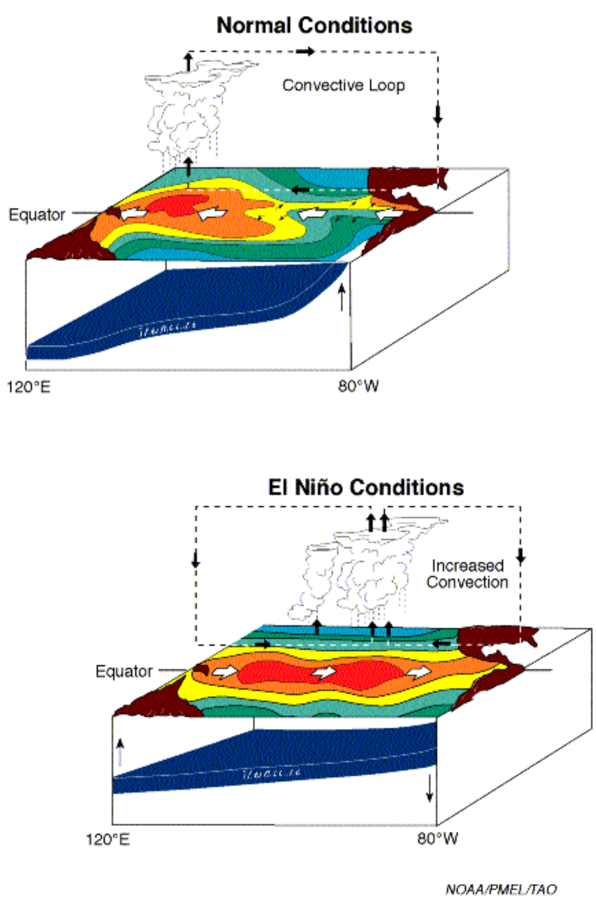


Figure 3-8. Depictions of ENSO Warm and Normal in the Cycle.
Source: National Oceanic and Atmospheric Administration, Pacific Marine Environmental Lab, TAO Array, http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html.

In normal, non-El Niño conditions (top panel of schematic diagram), the trade winds blow towards the west across the tropical Pacific. These winds pile up warm surface water in the west Pacific, so that the sea surface is about 1/2 meter higher at Indonesia than at Ecuador.

The sea surface temperature is about 8 degrees Celcius higher in the west, with cool temperatures off South America, due to an upwelling of cold water from deeper levels. This cold water is nutrient-rich, supporting high levels of primary productivity, diverse marine ecosystems, and major fisheries. Rainfall is found in rising air over the warmest water, and the east Pacific is relatively dry. The observations at 110 W (left diagram of 110 W conditions) show that the cool water (below about 17 degrees C, the black band in these plots) is within 50m of the surface.

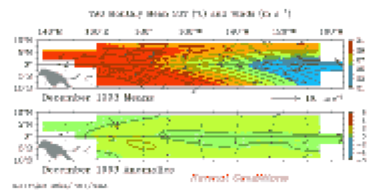
During El Niño (bottom panel of the schematic diagram), the trade winds relax in the central and western Pacific leading to a depression of the thermocline in the eastern Pacific, and an elevation of the thermocline in the west. The observations at 110W show, for example, that during

1982-1983, the 17-degree isotherm dropped to about 150m depth. This reduced the efficiency of upwelling to cool the suface and cut off the supply of nutrient rich thermocline water to the euphotic zone. The result was a rise in sea surface temperature and a drastic decline in primary productivity, the latter of which adversely affected higher trophic levels of the food chain, including commercial fisheries in this region. The weakening of easterly tradewinds during El Niño is evident in this figure as well. Rainfall follows the warm water eastward, with associated flooding in Peru and drought in Indonesia and Australia. The eastward displacement of the atmospheric heat source overlaying the warmest water results in large changes in the global atmospheric circulation, which in turn force changes in weather in regions far removed from the tropical Pacific.

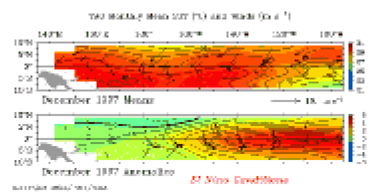
Recognizing El Niño

El Niño can be seen in Sea Surface Temperature in the Equatorial Pacific Ocean

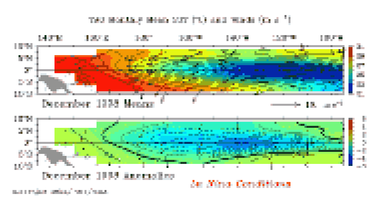
El Niño can be seen in measurements of the sea surface temperature, such as those shown above, which were made from the TAO Array of moored buoys. In December 1993, the sea surface temperatures and the winds were near normal, with warm water in the Western Pacific Ocean (in red on the top panel of December 1993 plot), and cool water, called the "cold tongue" in the Eastern Pacific Ocean (in green on the top panel of the December 1993 plot). The winds in the Western Pacific are very weak (see the arrows pointing in the direction the wind is blowing towards), and the winds in the Eastern Pacific are blowing towards the west (towards Indonesia). The bottom panel of the December 1993 plot shows anomalies, the way the sea surface temperature and wind differs from a normal December. In this plot, the anomalies are very small (yellow/green), indicating a normal December. December 1997 was near the peak of a strong El Niño year. In December 1997, the warm water (red in the top panel of the December 1997 plot) has spread from the western Pacific Ocean towards the east (in the direction of South America), the "cold tongue" (green color in the top panel of the December 1997 plot) has weakened, and the winds in the western Pacific, usually weak, are blowing strongly towards the east, pushing the warm water eastward. The anomalies show clearly that the water in the center of Pacific Ocean is much warmer (red) than in a normal December.



Normal Conditions - December 1993



El Niño (warm) Conditions - December 1997



La Niña (cold) Conditions - December 1998

December 1998 was a strong La Niña (cold) event. The cold tongue (blue) is cooler than usual by about 3° Centigrade. The cold La Niña events sometimes (but not always) follow El Niño events (http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html).

3.5.1.2 Pacific Effects of El Niño

ENSO events vary during each event and are categorized as “strong, moderate, or weak” events. This variation in the strength of the ENSO event means that the impacts that are experienced on land will also vary. Pacific Islands, which sit amidst the earth’s climate system, feel the impacts directly as the ocean water around the islands warms and the rainfall patterns change significantly, depending on the geographical position of the island related to the “warm pool.” Some islands experience wetter than normal conditions in weak events, but many of the islands become drier than normal. Rainfall decreases can be significant as to precipitate drought, especially in areas that rely on rainfall surface water catchments for the primary water supply. When the cycle moves into La Nina phase, where the water begins to cool, some of the islands experience heavy rainfall and flooding.

Many of the effects may also be termed “extreme climate events” that include the hazards mentioned in this chapter. This refers primarily to extremes in water availability---flooding or drought, tropical storms, and extremes in temperature---freezing or heat.

Other significant impacts in the Pacific have been noted as well, including: tropical cyclones generating further east because of the warm waters; sea level variation as thermal expansion from warm water raises sea level and alternatively decreases sea level significantly as the water cools; increased risk of wildfires associated with drought; coastal erosion with changes in sea level and storm impacts; coral reef bleaching (and coral reefs protect islands from waves and storm impacts); loss of plants, agriculture, and degradation of habitat; and, landslides associated with heavy rainfall.

The figures on the next few pages show the variation in rainfall based on the January, February, and March average rainfall. The years are listed from lowest to highest rainfall, with similar ENSO events depicted in red. This graphic demonstrates that ENSO events do not behave the same in Hawaii. ENSO years may be wetter than normal or drier than normal depending on the strength of the event. With different events, Hawai‘i can potentially experience severe droughts with associated wildfires or severe flooding.

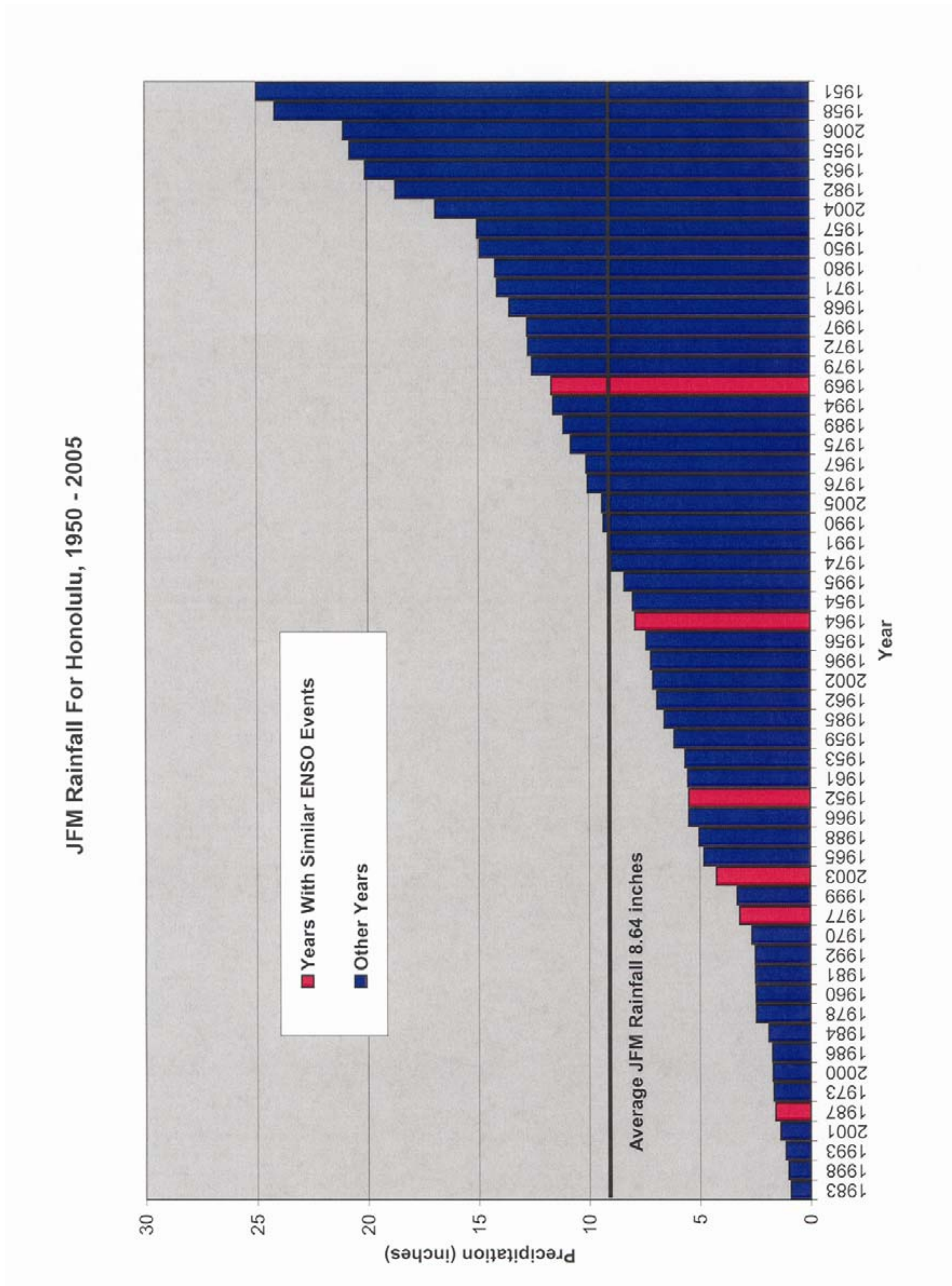


Figure 3-10. Rainfall for Honolulu, 1950-2005. ***Source***: NOAA National Weather Service and the Pacific ENSO Applications Center, http://www.soest.hawaii.edu/MET/Enso/index2.html.

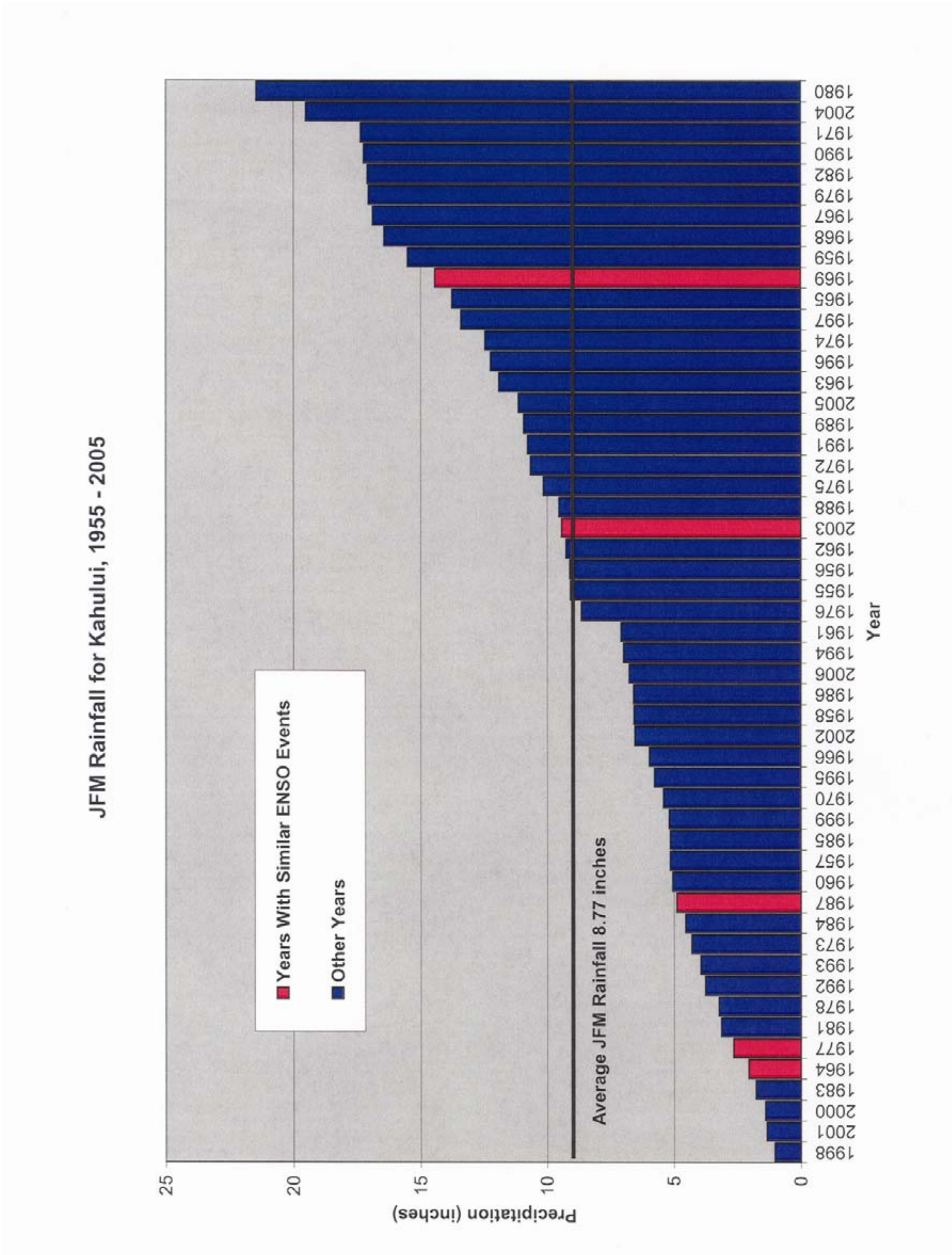


Figure 3-11. Rainfall for Kahului, 1950-2005. ***Source***: NOAA National Weather Service and the Pacific ENSO Applications Center, http://www.soest.hawaii.edu/MET/Enso/index2.html.

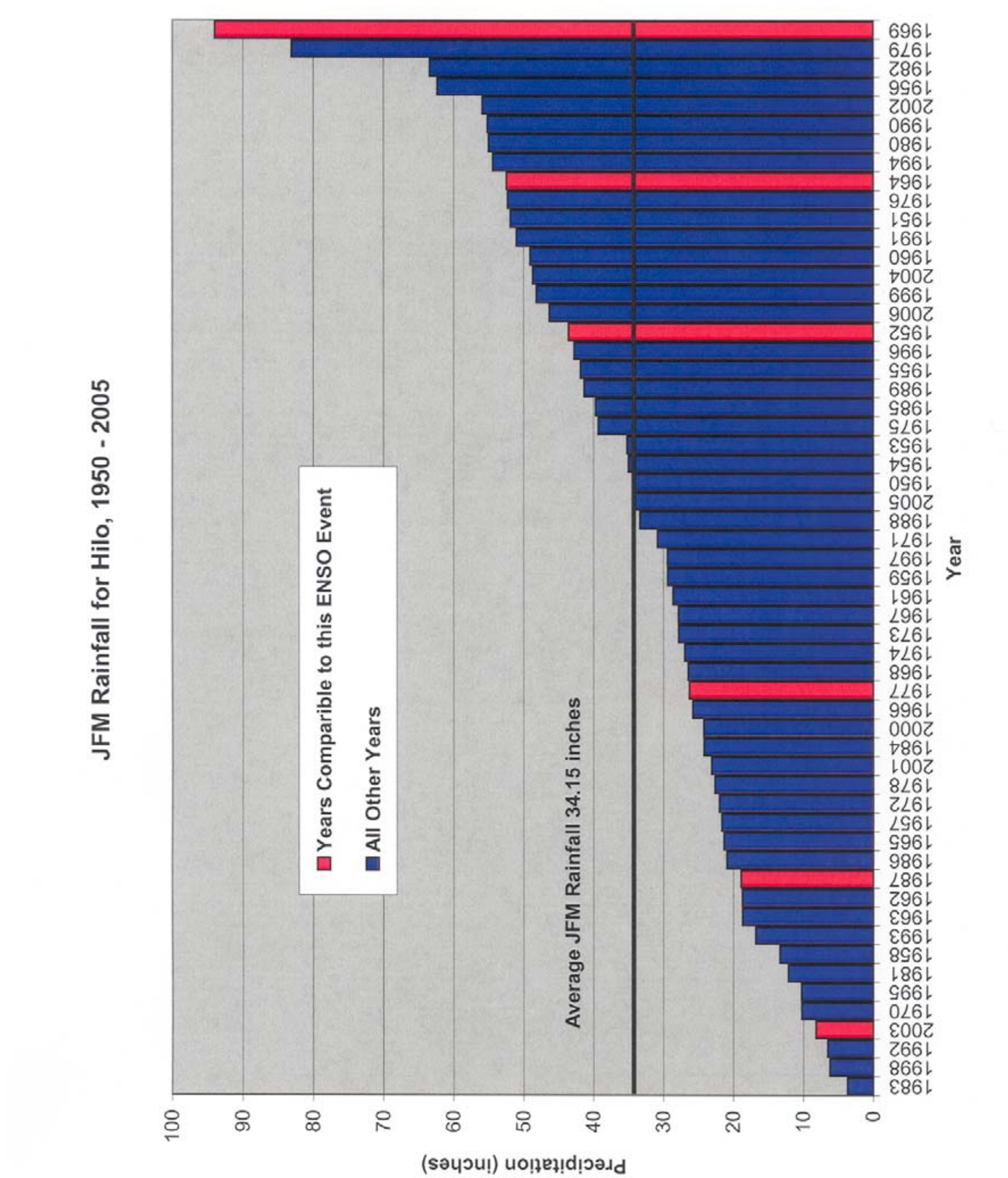


Figure 3-12. Rainfall for Hilo, 1950-2005. ***Source***: NOAA National Weather Service and the Pacific ENSO Applications Center, http://www.soest.hawaii.edu/MET/Enso/index2.html.

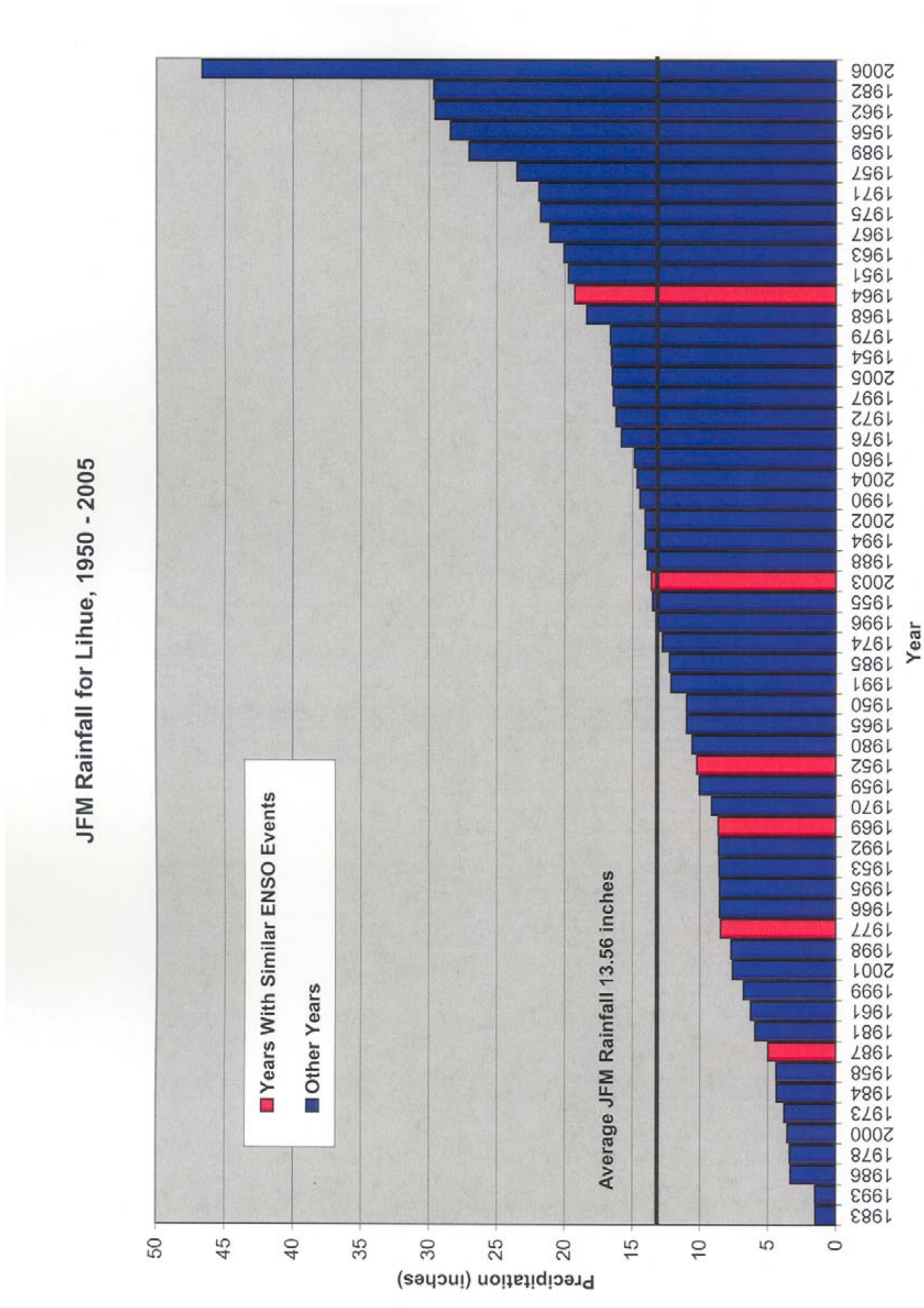


Figure 3-13. Rainfall for Līhu‘e, 1950-2005. ***Source***: NOAA National Weather Service and the Pacific ENSO Applications Center, http://www.soest.hawaii.edu/MET/Enso/index2.html.

By trying to understand the patterns in climate variability, each location may be able to develop better information to reduce risks from hazards associated with different types of ENSO events. The same patterns can be tracked for La Nina. These can be tracked at each rain gauge location and trends can be analyzed over time.

3.5.2 Climate Change

Hawaiʻi experiences a range of impacts to the environment, ecosystems, and ultimately the economy as a result of climate variation. These impacts identified at workshops and in a report Pacific Regional Assessment on the Consequences of Climate Variability and Change (Shea et. al. 2001, http://www.eastwestcenter.org/publications/search-for-publications/browse-alphabetic-list-of-titles/?class_call=view&pub_ID=1299&mode=view). The focus was on understanding sectoral impacts, yet the framework for the workshop tried to address issues in a proactive way, and enabled participants with different knowledge to work together and bring many perspectives, from business people, climate scientists, and cultural practitioners.

Water became the connecting theme that all of the workshop breakout sessions stressed in discussions and ties short-term variability with long-term trends for climate change.. Recommendations made from Hawaiian participants in the assessment included: 1) enhancing water resources because Hawaiʻi experiences drought, and water availability affects every sector of economic and livelihood importance in Hawaii; 2) protect marine and coastal resources because these ecosystems provide resilience and these ecosystems may be impacted in many ways from climate change; 3) protect infrastructure and ensure public safety because there will be increased likelihood of hazard risks; 4) protect public health because the changes in climate may make infectious diseases more prevalent and will increase risks associated with water-borne illnesses; 5) protect agricultural resources by increasing water availability, improving informational tools and forecasts to help in seasonal planting, and developing drought-resistant food crops; and 6) protecting tourism by incorporating risk managers, hotel associations, and the visitors bureau in planning ways to accommodate tourism, which is vital to local economic viability, and to ensure that there are adequate resources and safety for the residents of Hawaiʻi.

The same assessment mentioned previously further considered the impacts from longer term climate change issues. The Global Climate Models available at the time of the assessment did not have clear scenarios and impact predictions. The global models have not been scaled to assess local impacts adequately, although they work better for larger land masses than they do for islands in the Pacific Ocean.

By assessing impacts related to climate variability, some scenarios could be developed should climate extremes become more frequent. The workshops engaged government decision makers, resource experts, private sector representatives, and cultural practitioners in discussions about potential impacts under different climate scenarios, where there may be more frequent extremes and increased hazard risks. It is possible to pose scenarios and determine a range of mitigation actions and adaptation strategies, but it is still difficult to determine a good cost analysis of climate change impacts.

Proposals have been made to pursue development of socioeconomic assessment to influence policies. These will rely on downscaling information reported in the Fourth Assessment of the Intergovernmental Panel on Climate Change (http://www.ipcc.ch/). The best available knowledge provides a range of impacts and changes, such as sea level projections. The impacts will be different for each localized area depending on geography, geology, bathymetry, atmospheric conditions, and other variables that need to be assessed to determine local risks.

The Summary for Policymakers of the IPCC Working Group II report on Impacts, Adaptation and Vulnerability have observed the following impacts that are currently taking place. The document can be found online in full at the IPCC Fourth Assessment report website (http://www.ipcc.ch/). The main points are copied below, with subpoints of major relevance to the State of Hawai‘i in the context of disaster risk reduction.

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.

A global assessment of data since 1970 has shown it is likely[6] that anthropogenic warming has had a discernible influence on many physical and biological systems.

Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers.

More specific information is now available across a wide range of systems and sectors concerning the nature of future impacts, including for some fields not covered in previous assessments.

- Fresh water resources and their management
- Ecosystems
- Food, fiber, and forest products
- Industry, settlement, and society
- Heatlh
- Coastal systems and low-lying areas
    - Coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea-level rise. The effect will be exacerbated by increasing human-induced pressures on coastal areas. *** D [6.3, 6.4]
    - Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surfacetemperature of about 1-3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatization by corals. *** D [B6.1, 6.4]
    - Coastal wetlands including salt marshes and mangroves are projected to be negatively affected by sea- level rise especially where they are constrained on their landward side, or starved of sediment. *** D[6.4]
    - Many millions more people are projected to be flooded every year due to sea-level rise by the 2080s.

- Those densely-populated and low-lying areas where adaptive capacity is relatively low, and which already face other challenges such as tropical storms or local coastal subsidence, are especially at risk.
- The numbers affected will be largest in the mega-deltas of Asia and Africa while small islands are especially vulnerable. *** D [6.4]
- Adaptation for coasts will be more challenging in developing countries than in developed countries, due to constraints on adaptive capacity. ** D [6.4, 6.5, T6.11]

More specific information is now available across the regions of the world concerning the nature of future impacts, including for some places not covered in previous assessments.

Small islands

- Small islands, whether located in the tropics or higher latitudes, have characteristics which make them especially vulnerable to the effects of climate change, sea level rise and extreme events. *** D [16.1,16.5]
- Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources, e.g., fisheries, and reduce the value of these destinations for tourism. ** D [16.4]
- Sea-level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities. *** D [16.4]
- Climate change is projected by the mid-century to reduce water resources in many small islands, e.g., in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low rainfall periods. *** D [16.4]
- With higher temperatures, increased invasion by non-native species is expected to occur, particularly on middle and high-latitude islands. ** N [16.4]

Magnitudes of impact can now be estimated more systematically for a range of possible increases in global average temperature.

The following graphic comes from the same report. It generally shows the expected changes to various ecosystems based on increased temperature as much as 5 degrees Celcius. As the figure shows, there are predictions of increased hazards. The graphic also indicates that rising global temperatures in tropical areas will result in decreased water availability. Health of many ecosystems, such as the coral reefs that provide shoreline protection, will be compromised and many species will not survive.

Figure 3-14. **Key impacts as a function of increasing global average temperature change**

(Impacts will vary by extent of adaptation, rate of temperature change, and socio-economic pathway)

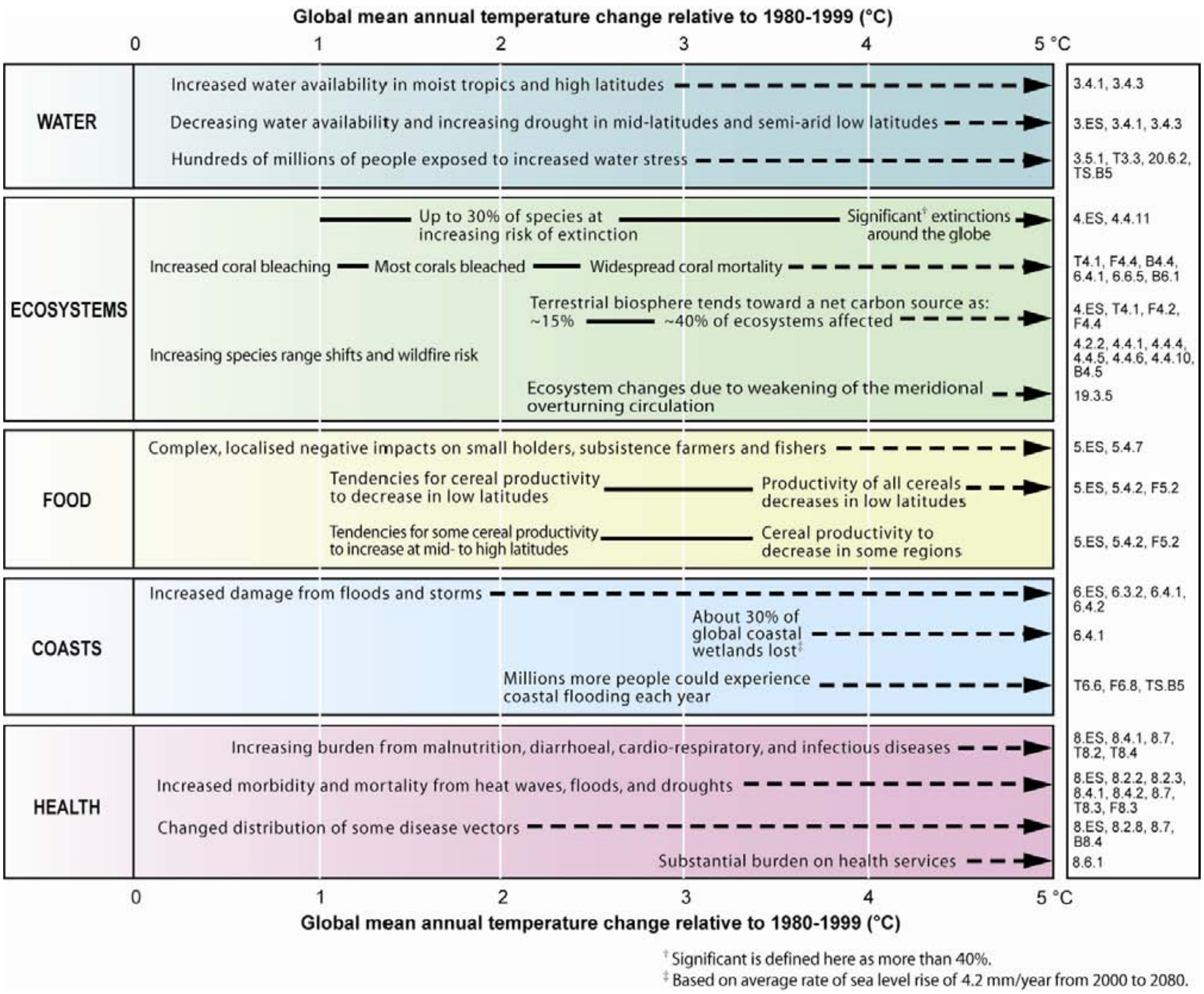


Table SPM-1. Illustrative examples of global impacts projected for climate changes (and sea-level and atmospheric carbon dioxide where relevant) associated with different amounts of increase in global average surface temperature in the 21st century [T20.7]. The black lines link impacts, dotted arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left hand side of text indicates approximate onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of Special Report on Scenarios (SRES) scenarios A1FI, A2, B1 and B2 (see Endbox 3). Adaptation to climate change is not included in these estimations. All entries are from published studies recorded in the chapters of the Assessment. Sources are given in the right hand column of the Table. Confidence levels for all statements are high. ***Source:*** **Table copied in full from: Climate Change 2007: Impacts, Adaptation and Vulnerability, Summary for Policy Makers, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report, p.13, 13 April 2007, http://www.ipcc.ch/.**

Table 3-23. Impacts due to altered frequencies and intensities of extreme weather, climate, and sea level events are very likely to change.

Phenomena and direction of trends	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems [4.4, 5.4]	**Water resources [3.4]**	**Human health [8.2]**	**Industry, settlement and society [7.4]**
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snow melt; effects on some water supply	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; wild fire danger increase	Increased water demand; water quality problems, e.g., algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially-isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on elderly, very young and poor.
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to water logging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries, infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought	Likely	Land degradation,	More widespread	Increased risk of food and	Water shortages for settlements,

increases		lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	water stress	water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	industry and societies; reduced hydropower generation potentials; potential for population migration

[a] See Working Group I Fourth Assessment Table 3.7 for further details regarding definitions
[b] Warming of the most extreme days and nights each year
[c] Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
[d] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period [Working Group I Fourth Assessment 10.6]. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Table SPM-2. Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid to late 21st century. These do not take into account any changes or developments in adaptive capacity. Examples of all entries are to be found in chapters in the full Assessment (see source at top of columns). The first two columns of this table (shaded yellow) are taken directly from the Working Group I Fourth Assessment (Table SPM-2). The likelihood estimates in Column 2 relate to the phenomena listed in Column 1. The direction of trendand likelihood of phenomena are for IPCC SRES projections of climate change.

***Source:* Table copied in full from: Climate Change 2007: Impacts, Adaptation and Vulnerability, Summary for Policy Makers, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report, p.14, 13 April 2007, http://www.ipcc.ch/.**

3.5.3 Sea Level Rise

Global and local sea level change is of profound interest to researchers and planners due to it enormous potential impact on human populations living in coastal regions. Global sea level is projected to rise during the 21st century at a greater rate than during 1961 to 2003. One estimate from the IPCC Special Report on Emission Scenarios (SRES) A1B scenario by the mid- 2090s, forecasts that global sea level will be 0.44 m above 1990 levels, and continue rising at about 4 mm yr–1. As we have seen in the past, sea level change in the future will not be geographically

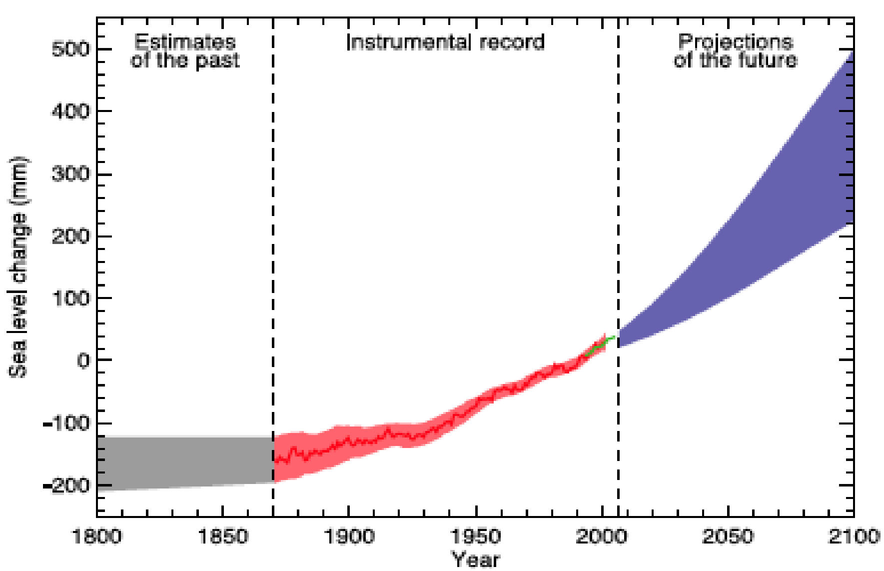


Figure 3-15. Time series of global mean sea level (deviation from the 1980-1999 mean) in the past and as projected for the future (IPCC, 2007b).

uniform, with some model projections predicting regional sea level change varying about ±0.15 m of the mean (Figure 8). Thermal expansion is projected to contribute more than half of the average rise, but land ice will lose mass increasingly rapidly as the century progresses.

A brief evaluation of current sea level rise projections for this century produces a wide range of estimates. Table 1 offers a summary of recent relevant research on sea level projections utilized in the damage scenarios.

Table 3-24. Sea Level Rise Estimates.

Sea level Rise Estimate	Source	Notes
0.2m to 0.6m.	IPCC (2007)	Estimate recognizes lack of modeled contribution from ice sheet wasting.
0.5m. to 1.5m	Rahmstorf (2007)	Uses linear projection of sea level based on temperature correlations from past century to produce sea level rise estimate this century.
2.0 to 3.0 m	Otto-Blienser, 2006	
3.0 to 5.0 m	Overpeck, *et al* 2006	Lead author for IPCC Working Group I report Paleo climate and Geologic records indicate ice sheet disintegration can yield sea level rise on the order several meters per century.
Several meters.	Hansen et al (2005)	
5+ meters.	Hansen (2007) (unpublished)	Based on energy imbalance could produce sea level rise of 1 m/decade.

Sea level changes may be due to a variety of factors. Impacts may be seen in changes to shorelines and in coastal erosion, so additional discussion of sea level change appears later in section 3.

Whereas sea level changes occurring as a result of global climate change will impact all (US) coastal areas, Hawai‘i’s shorelines will be unique uniquely affected as a result of island subsidence processes. Because of loading of the Pacific tectonic plate by the growth of Hawai‘i’s volcanoes, lithostatic flexure (down-bowing) of the plate, as well as compaction of the volcanic products, causes the islands to sink at a measurable rate. The southern half of Hawai‘i island is subsiding at a rate of 2.5 mm/year (25 cm/100 years); the older islands are subsiding at a somewhat slower rate. These rates are all additive to sea level rise resulting from those associated with global climate change.

3.6 Earthquakes

3.6.1 Seismic Hazard

Unlike many other areas where a shift in tectonic plates is the sole cause of an earthquake, 95% of earthquakes in Hawai‘i are linked to volcanic activity. These earthquakes can occur before or during eruptions, or as molten rock travels underground. A few of the island's earthquakes are less directly related to volcanism; these earthquakes originate in zones of structural weakness at the base of the volcanoes or deep within the earth beneath the islands.

Table 3-25. Estimated Earthquake

Estimated Future Earthquake Losses in the County of Hawaii

County	Expected Annual Earthquake Losses per $Million of Building Value
San Francisco, CA	$3,200
San Jose, CA	$3,000
County of Hawaii	$2,900
Oakland, CA	$2,900
Eureka, CA	$2,900
Ventura, CA	$2,800
Riverside, CA	$2,700
Santa Cruz, CA	$2,600
Los Angeles, CA	$2,300
Santa Rosa, CA	$2,300

The Top Ten Counties of Earthquake Risk in the United States
Ranked by estimated future Annual Earthquake Loss Ratio (AELR)
(Annual loss per million dollars of building value)

Strong earthquakes endanger people and property by shaking structures and by causing ground cracks, ground settling, and landslides. Strong earthquakes in Hawaii's past have destroyed buildings, water tanks, and bridges, and have disrupted water, sewer, and utility lines. Ground shaking during an earthquake varies within a small area, depending on the nature of the underlying ground (e.g., lava bedrock or soil). Local topography also affects earthquake hazards. Steep slopes composed of loose material may produce large landslides during an earthquake. The type of construction also affects the risks of damages to a property. For these reasons, earthquake hazards are highly localized and it is difficult to assign regional earthquake boundaries that share the same relative degree of hazard. As shown in Table 3-36, the County of Hawai‘i ranks third in the estimated future earthquake losses, and it is important to develop a strong understanding of potential losses and damage to mitigate the impacts of earthquake hazards in the State of Hawai‘i.

Scientists portray earthquake shaking using several parameters, including magnitude, intensity, and peak ground acceleration (PGA) to understand damage and to develop building codes and mechanisms to reduce earthquake risk. The Richter Scale measures magnitude. An earthquake of 5.0 is a moderate event, 6.0 is a strong event, 7.0 is a major earthquake, and a "great quake" exceeds 8.0. For each whole number increase, there is a 10-fold jump in seismic wave amplitude (or, a 30-fold gain in energy released). For example, a 6.0 earthquake generates 30 times more energy than a 5.0

quake and 900 times (30*30) greater than a 4.0 earthquake. In the United States, the Modified Mercalli Intensity Scale (MMI) measures intensity - the effects of an earthquake felt by people. MMI ranges from I (faintly registered by instruments) to XII (nearly total destruction). Ratings decrease with increasing distance away from an earthquake's source.

Table 3-26. Peak Ground Acceleration Conversion.

Table Shows Conversion of MMI to PGA (%g) Values Specific to Hawaii (Based on Wyss & Koyanagi 1992)

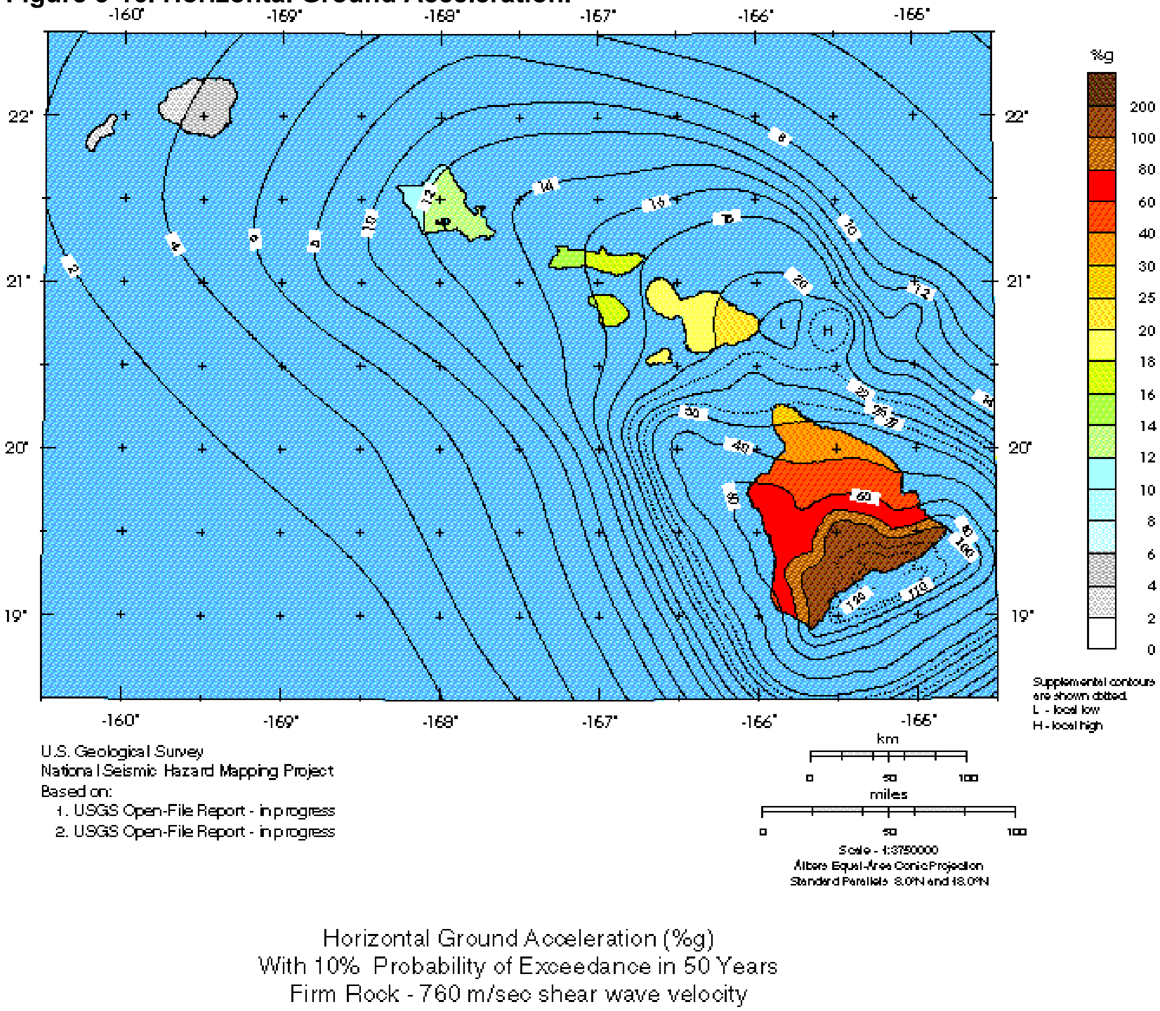
Near-Source Modified Mercalli Intensity (MMI)	I	II-III	IV	V	VI	VII	VIII	IX	X
Maximum Peak Ground Acceleration (PGA) in %g	< 3.2	3.2 - 8.1	8.1 - 13	13 - 20	20 - 32	32 - 51	51 - 80	80 - 128	> 128
Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very Light	Light	Moderate	Moderate / Heavy	Heavy	Very Heavy
Magnitude	—	—	—	< 5.5	5.5	6.0	6.5	7.0	7.5

Source: USGS, Wyss and Koyanagi, 1992.

There are a number of probability levels and ground motion parameters to choose from at the USGS website http://pubs.usgs.gov/imap/i-2724/. The 10% exceedance in 50-year Peak Ground Acceleration maps may be the most appropriate single map for planning at the current time, because they will be expressed for an equivalent parameter as past Uniform Building (UBC) codes.

The following illustration shows the higher Peak Ground Accelerations expected throughout the state that exceeds the maximum accelerations embedded in the pre-1997 UBC codes zonations. Accordingly, the areas of historically under-designed buildings can potentially be identified based on the past seismic code zonation history.

Figure 3-16. Horizontal Ground Acceleration.



Source: USGS. Seismic-Hazard Maps for Hawaii. F.W. Klein, A.D. Frankel, C.S. Mueller, R.L. Wesson, *and* P.G. Okubo

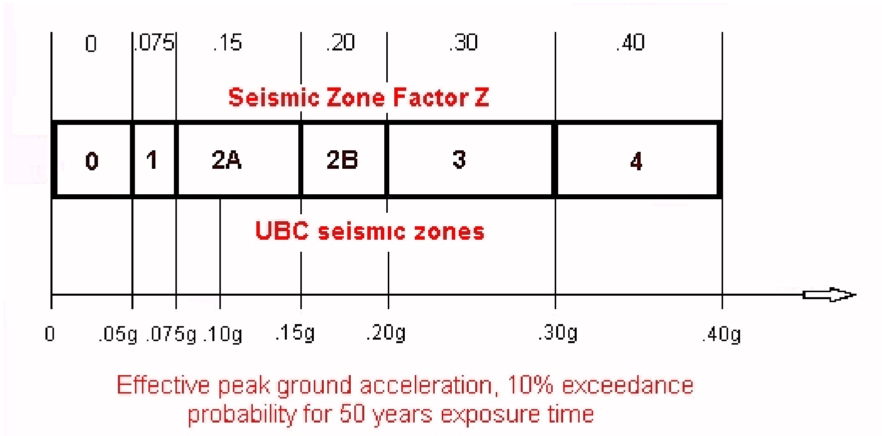
In 1992, the USGS was asked to reevaluate the seismic hazards in Hawaii County. A probabilistic seismic-hazards assessment was carried out according to previously established procedures.

Seismic-hazards analysis combines:

- Earthquake rates known from the historical record
- Information about how strong ground shaking dissipates with increasing distance from the earthquake
- Determination of the probabilities that specified levels of ground motion will occur in a specified time period

The UBC seismic provisions contain six seismic zones, ranging from 0 (no chance of severe ground shaking) to 4 (10% chance of severe shaking in a 50-year interval). The shaking is quantified in terms of g-force, the earth's gravitational acceleration. The diagram below is a way of describing seismic zonation.

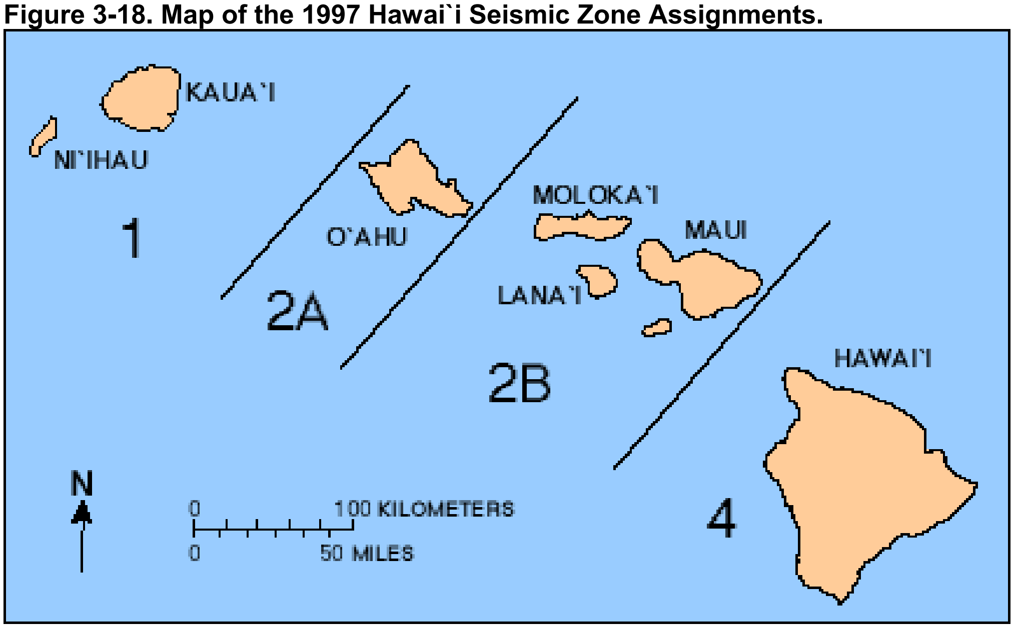
Figure 3-17. Seismic Zonation.



Source: Hawaii Volcanoes Observatory, USGS. http://hvo.wr.usgs.gov/earthquakes/hazards/

The new calculations indicate that Hawai'i County has a greater chance of strong ground shaking than was previously thought. The following map shows Hawai'i seismic zone assignments as of 1997.

Figure 3-18. Map of the 1997 Hawai`i Seismic Zone Assignments.



Source: Hawai'i Volcanoes Observatory, USGS. http://hvo.wr.usgs.gov/earthquakes/hazards/

3.5.2 History of Earthquakes

Earthquakes are not only concentrated on the Island of Hawaiʻi. The Oʻahu Earthquake of 1948, which occurred along the Diamond Head Fault, was measured between 4.8 and 5.0 and resulted in broken store windows, plaster cracks, ruptures in building walls, and a broken underground water main.

In 1871, the Lānaʻi Earthquake had a magnitude of 7 or greater. Massive rock falls and cliff collapse occurred on Lanai as well as damages to homes. A house and several churches were flattened on the island of Maui and Molokaʻi. Two houses were reported to have split open on Oʻahu. And ground fractures and land slippage was reported in Waiʻanae and Lahaina.

Each year thousands of earthquakes occur in Hawaiʻi, with the majority of them too small to be felt except by highly sensitive instruments. However, there have also been earthquakes that jolted the islands. The following table shows the history of earthquakes in the State of Hawaiʻi. It is important to remember that these tremors in the state could easily result in a tsunami.

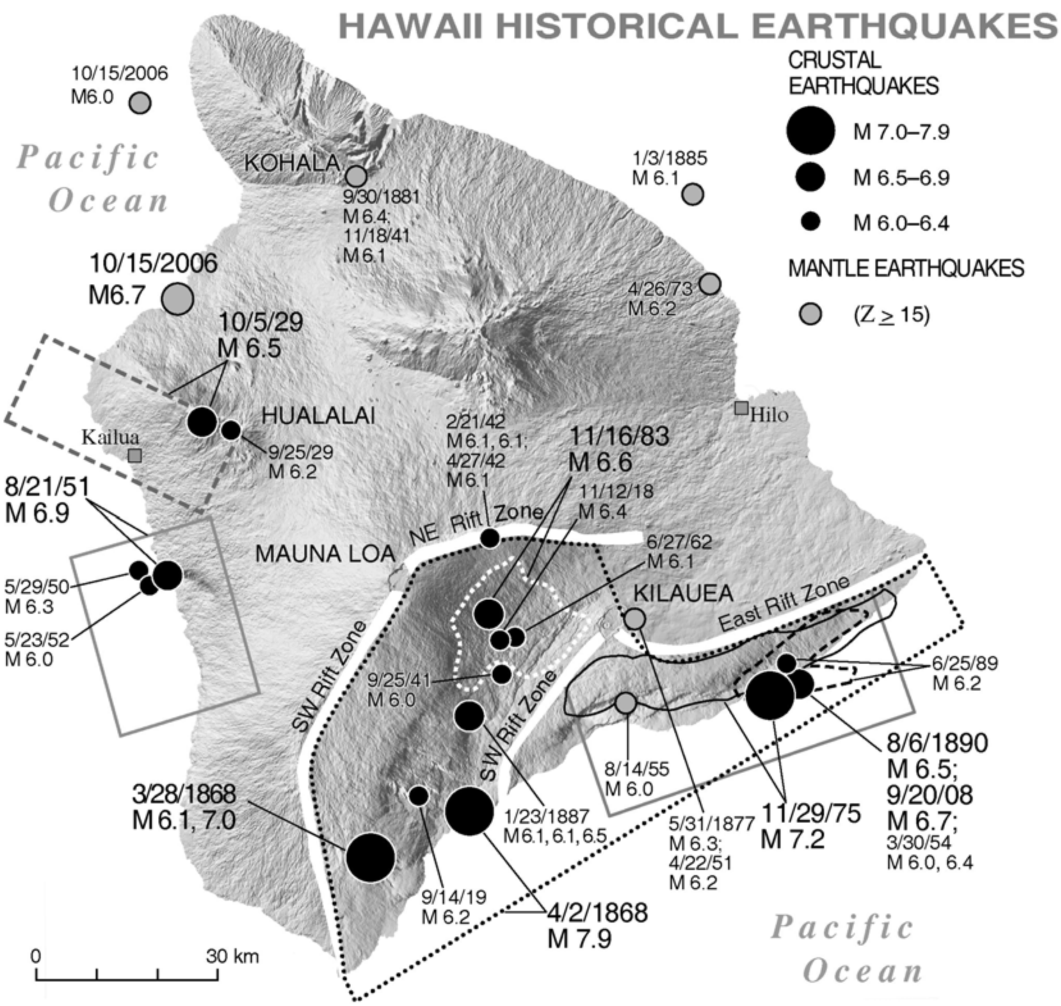
Table 3-27. History of Earthquakes in Hawaiʻi, M6 and Greater, 1868-Present.

Year	Date	Magnitude	Source
1868	Mar 25	6.5-7.0	Mauna Loa south flank
1868	Apr 2	7.5-8.1	Mauna Loa south flank
1918	Nov 2	6.2	Ka'oki, between Mauna Loa and Kilauea
1919	Sep 14	6.1	Ka'u District. Mauna Loa south flank
1926	Mar 19	>6.0	NW of Hawai'i Island
1927	Mar 20	6.0	NE of Hawaii Island
1929	Sep 25	6.1	Hualalai
1929	Oct 5	6.5	Hualalai
1938	Jan 22	6.9	N of Maui
1940	Jun 16	6.0	N of Hawaii Island
1941	Sep 25	6.0	Ka'oki
1950	May 29	6.4	Kona
1951	Apr 22 Aug 21	6.3 6.9	Lithospheric
1952	May 23	6.0	Kona
1954	Mar 30	6.5	Kilauea south flank
1955	Aug 14	6.0	Lithospheric

1962	Jun 27	6.1	Ka'oki
1973	Apr 26	6.3	Lithospheric
1975	Nov 29	7.2	Kilauea south flank
1983	Nov 16	6.6	Ka'oki
1989	Jun 25	6.1	Kalapani, Kilauea south flank
2006	Oct 15	6.7	Kīholo and Mahukona, Kohala side of the Island of Hawai'i.

Source: Atlas of Hawaii, Third Edition, 1998. Updated from US Geological Survey (USGS) data, http://earthquake.usgs.gov/regional/states/historical_state.php#hawaii.

Figure 3-19. Hawai'i Historical Earthquake Locations.

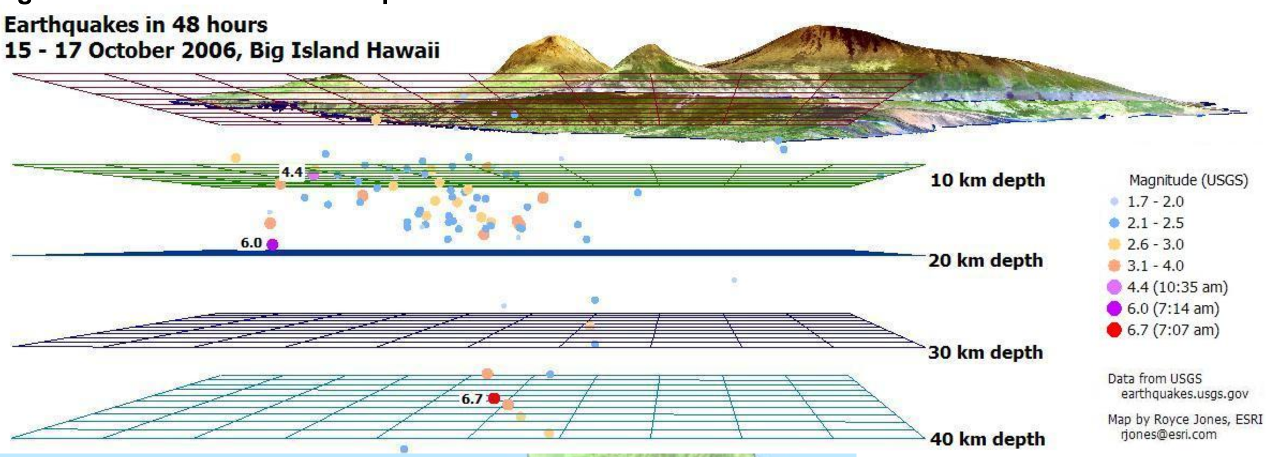


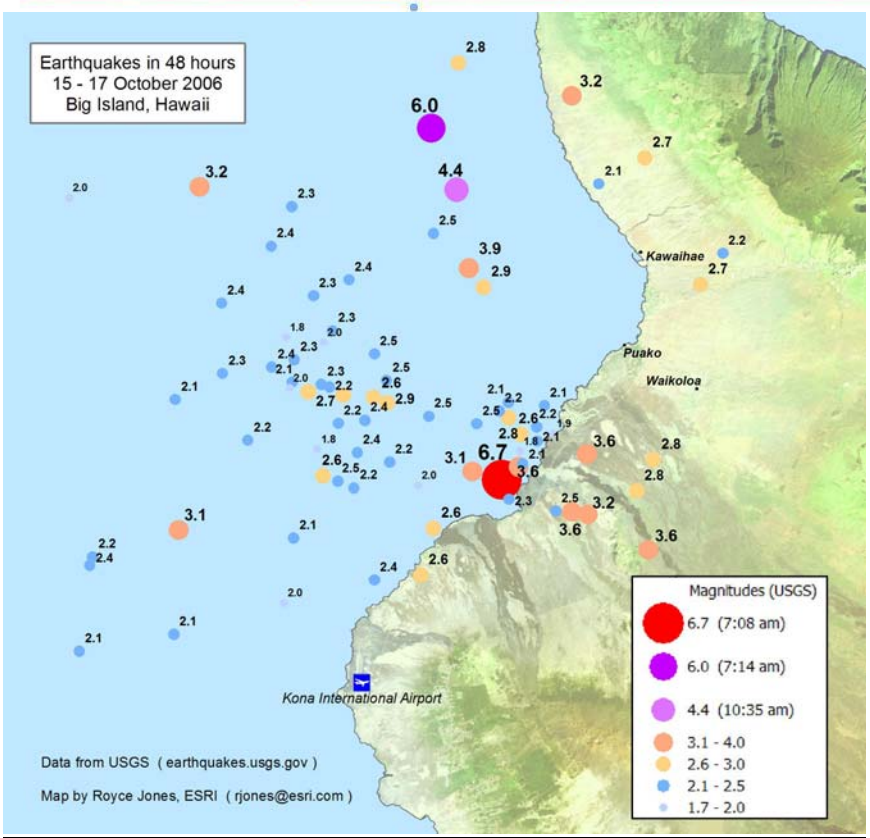
Source: Gary Chock, Martin & Chock, Inc. April 2007. From presentations to the Structural Engineers Association of Hawaii and the Hawaii State Earthquake Advisory Committee.

3.5.3 Recent Earthquakes

The Kīholo earthquake was the first earthquake greater than 6.0 magnitude in almost twenty years. It was not actually a single earthquake, and several aftershocks of lower magnitude followed for more than a month after the major tremors on October 15, 2007.

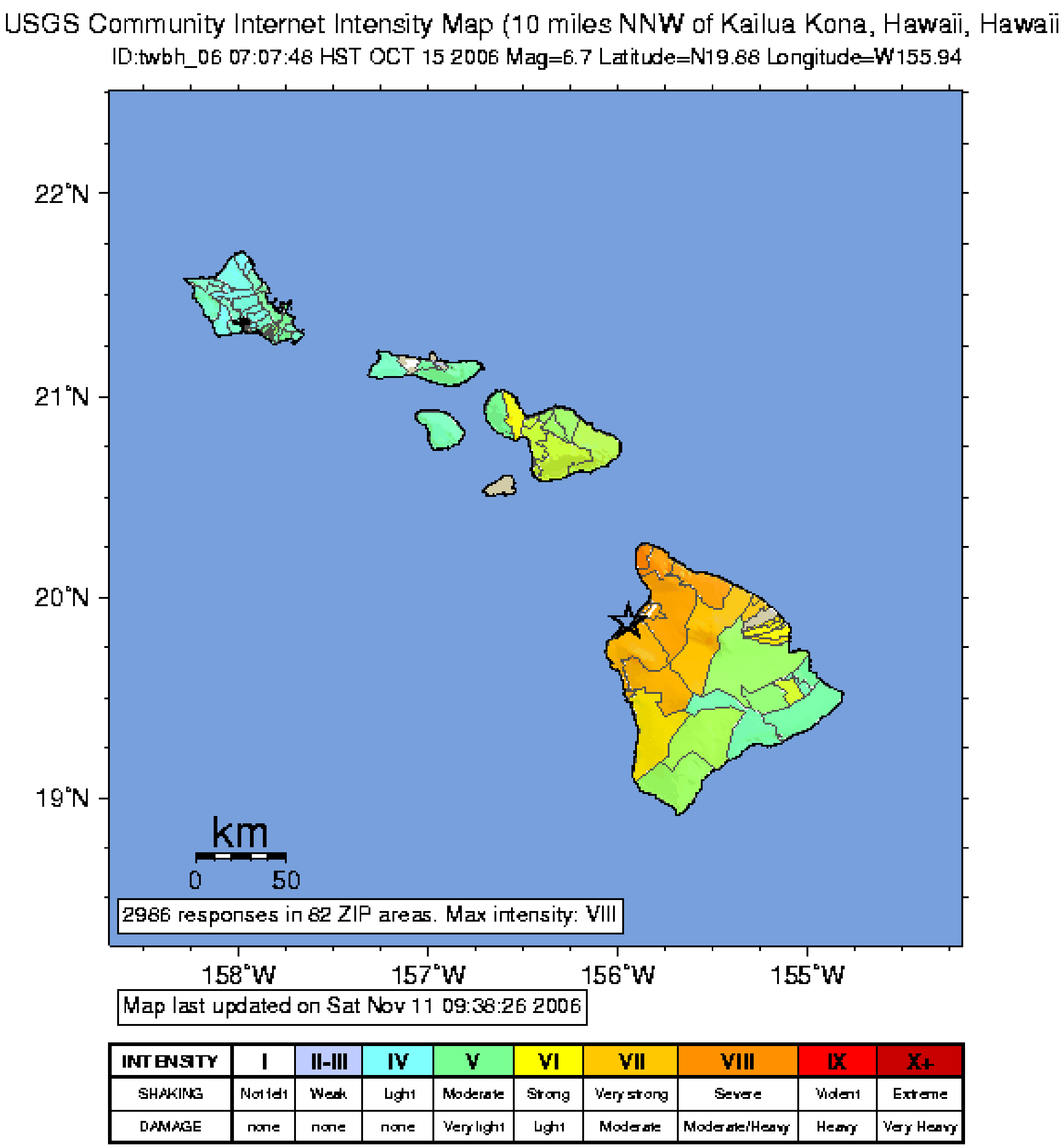
Figure 3-20a and 3-20b. Earthquakes in 48 hours.





Sources: Data from USGS 2006; Maps from Royce Jones, ESRI, 2006.

Figure 3-21. USGS Community Internet Intensity Map.



Sources: USGS 2006; Martin & Chock 2007.

Figure 3-22. Rockslides from the K‘holo Earthquake.

Figure 3-23. Rockfall Landslides near Housing from the Kīholo Earthquake.

Sources: Gary Chock, Martin & Chock, 2007, slides 20-21.

Figure 3-24. Damage to Highway 19 Near Pa‘auilo.

***Source*:** Gary Chock, Martin & Chock, Inc. 2007, slide 22.

Figures 3-25a and 3-25b. Kona Hospital Ceiling Damage.

***Source*:** Gary Chock, Martin & Chock, Inc. 2007, slide 24.

Figure 3-26. Hisaoka Gym in Kamehameha Park.

Source: Gary Chock, Martin & Chock, Inc. 2007, slide 26.

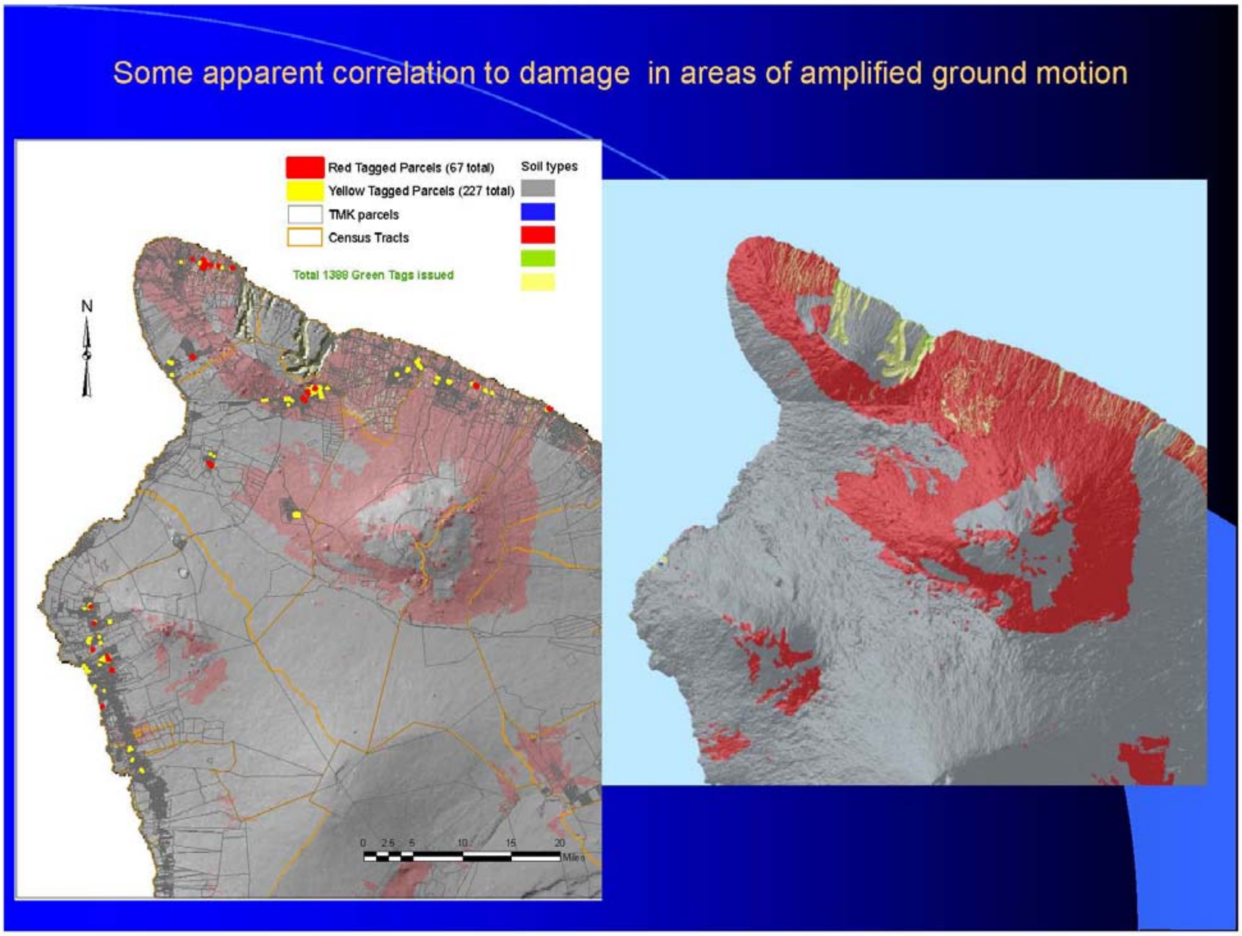
Figure 3-27. Mauna Kea Beach Hotel Damage.

Source: Gary Chock, Martin & Chock, Inc. 2007, slide 28.

Prior to the earthquake, trainings on post-disaster structural inspections were conducted for structural engineers and others with structural expertise. The ATC Training enabled available trained volunteers to assist the County of Hawaii with post disaster inspection. The ATC inspections reported the following (Chock 2007):

- The County reports that 1682 homes have been inspected as of last week (1016 were done in the first 7 days):
  - 67 Red (4%)
  - 227 Yellow (13%)
  - 1388 Green (83%)
- 231 of these homes were evaluated by SEAOH in one week, including several detailed re-evaluations
  - 36 Red (16%)
  - 48 Yellow (21%)
  - 147 Green (63%)
- Other buildings and structures, such as churches, were also inspected by SEAOH Members (not included in the above)
- American Red Cross did a windshield survey and reported 40 homes destroyed and 280 with major damage, and about 2009 with minor damage.
- FEMA reports 10 destroyed and 1627 damaged.

Figure 3-28. Correlation of Damage to Amplified Ground Motion.



Source: Gary Chock, Martin & Chock, Inc. 2007.

Figure 3-29. Damage by Construction Type.

SEAOH Breakdown by Frequency of Occurrence of Severity of Damage Within Type of Construction

Type of Construction	Red Within Type	Yellow Within Type	Green Within Type	Percentage of Type within the Total Number Evaluated
Conventional Slab on Grade	9%	7%	84%	29.0%
Post and Pier	18%	23%	59%	59.7%
Rock Masonry	12%	59%	29%	7.4%
Multistory CMU	33%	11%	56%	3.9%
All Categories	16%	21%	64%	100%

***Source*:** Gary Chock, Martin & Chock, Inc. April 2007, slide 43.

Figure 3-30. Damaged Facilities and Cost Six Months Post-Disaster.

Damage as of Dec 31 2006	Number of Facilities with Major Damage	Number of Facilities with Minor Damage	Estimated Cost ($ millions)
Hawaii County Buildings	15	7	16
Hawaii State Bldgs	1	21	0.5
University / Community Colleges	3	17	2.5
Public Schools	1	25	5
Libraries	0	3	0.2
Hospitals	2	3	3.5
Private Businesses	36	264	46+
Private Residences	304	1705	Pending; 10+
Hawaii County Bridges			0.2
State Bridges			7
Hawaii County Roads			3
State Highways			31
Harbors	1	1	7+ (up to 30)
Electric Utilities			4
Agricultural Damage	2	1	12
Reservoirs		2	Pending
State and National Parks	5	16	7
Total of Preliminary Estimates	370	2063	$155

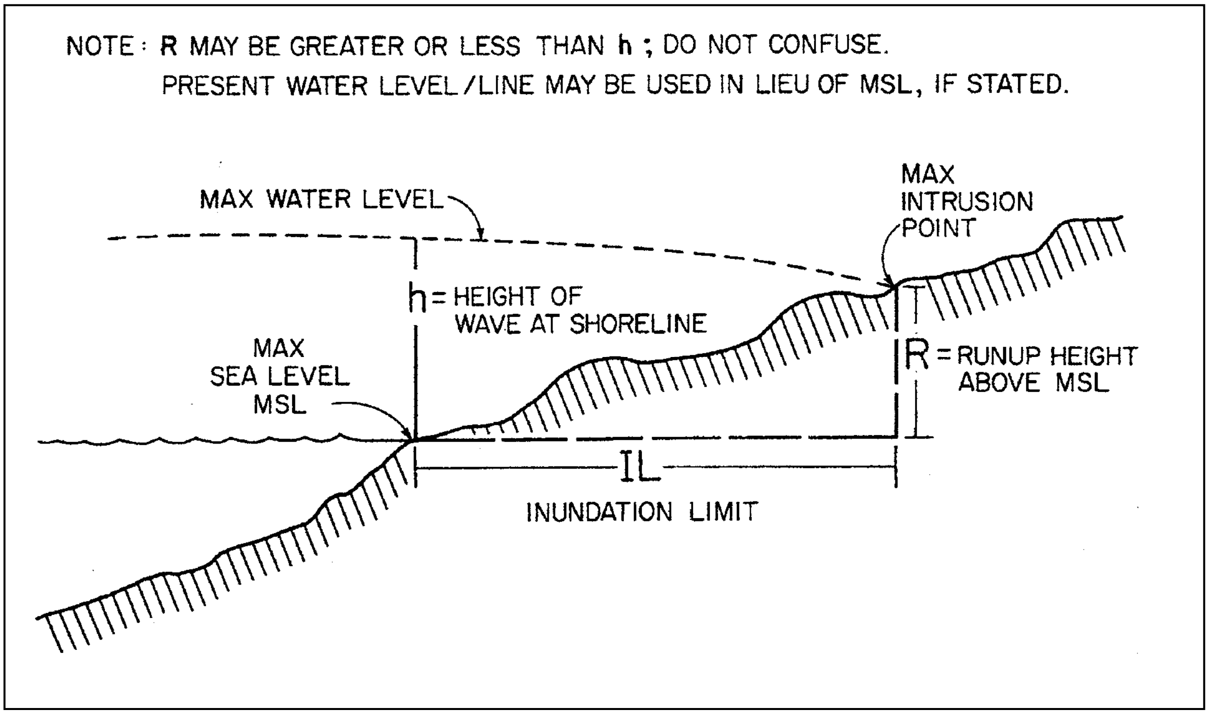
Damage as of 12/31/2006

***Source*:** Gary Chock, Martin & Chock, Inc. April 2007, slide 49.

3.7 Tsunami

A tsunami is a sea wave of local or distant origin that results from large-scale seafloor displacements associated with large earthquakes, major submarine slides, or catastrophic volcanic eruptions. Although landslides and volcanoes cause some tsunamis, probably 95 percent result from earthquakes -- usually under the ocean floor but occasionally beneath the coast.

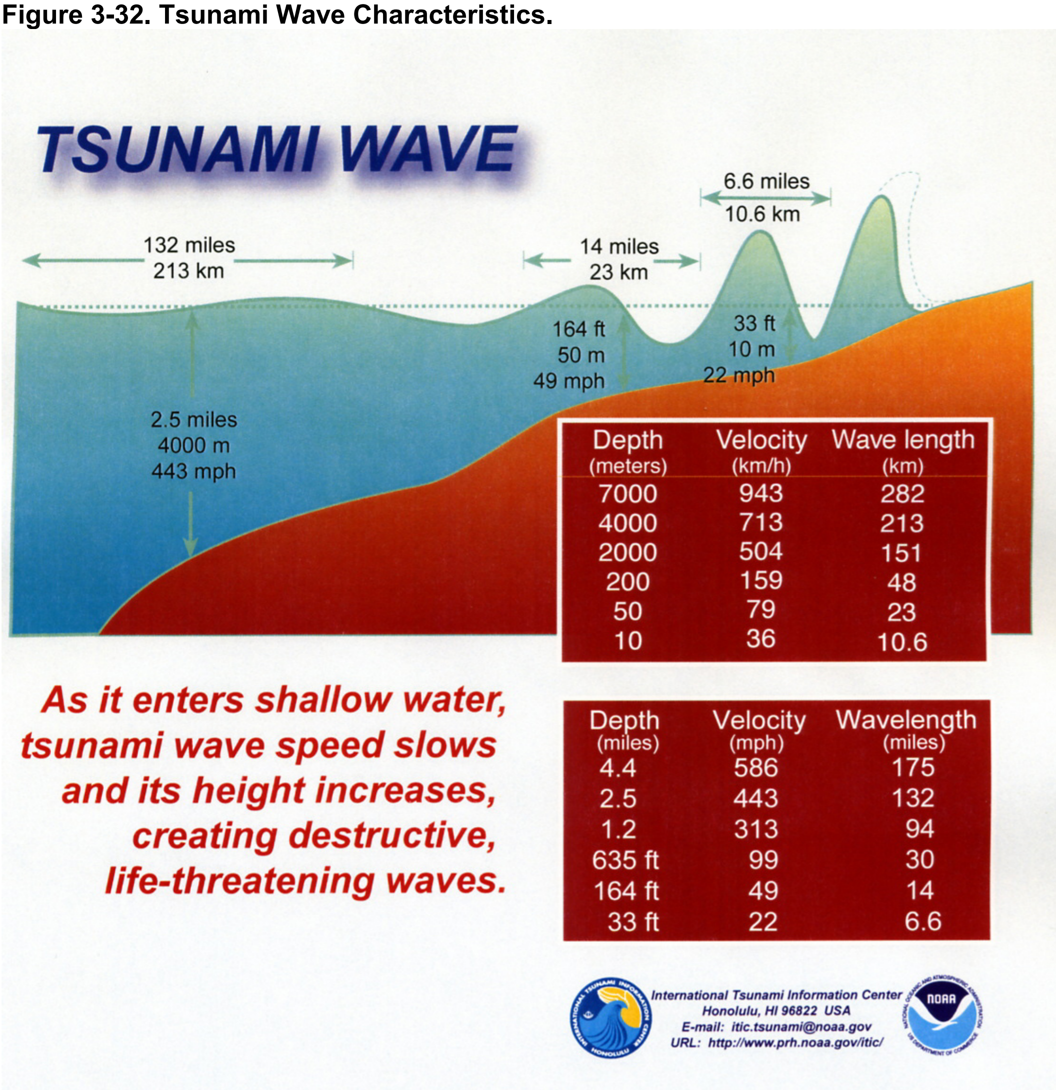
Figure 3-31. Definition of Tsunami Inundation Terms.



Tsunamis are characterized as shallow-water waves. Shallow-water waves are different from wind-generated surf waves, the waves many of us have observed at the beach. Wind-generated waves usually have a period (time between two successional waves) of five to twenty seconds and a wavelength (distance between two successional waves) of about 100 to 200 meters (300 to 600 ft). A tsunami can have a period in the range of five minutes to two hours and a wavelength in excess of 300 miles (500 km). It is because of their long wavelengths that tsunamis behave as shallow-water waves. A wave is characterized as a shallow-water wave when the ratio between the water depth and its wavelength gets very small. The speed of a shallow-water wave is equal to the square root of the product of the acceleration of gravity (32ft/sec/sec or 980cm/sec/sec) and the depth of the water. The rate at which a wave loses its energy is inversely related to its wavelength. Since a tsunami has a very large wavelength, it will lose little energy as it propagates. Hence in very deep water, a tsunami will travel at high speeds and propagate across transoceanic distances with limited energy loss. For example, when the ocean is 20,000 feet (6100 m) deep, unnoticed tsunami travel about 550 miles per hour (890 km/hr), the speed of a jet airplane. And they can move from one side of the Pacific Ocean to the other side in less than one day.

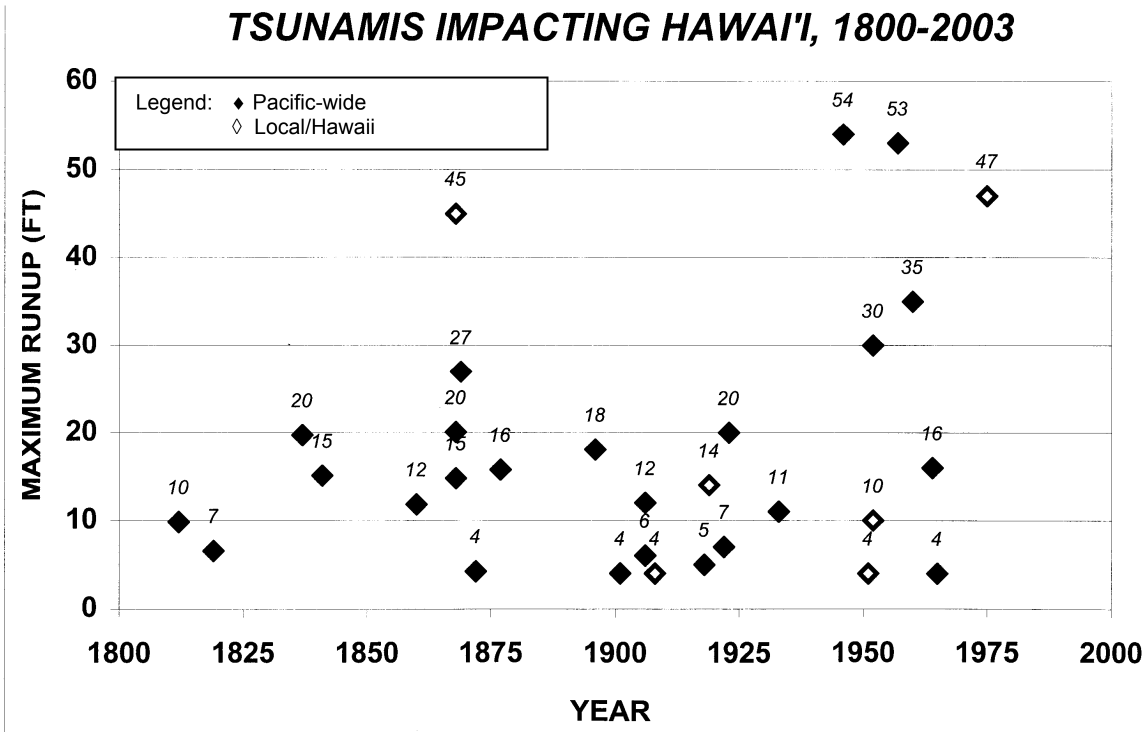
As a tsunami leaves the deep water of the open sea and propagates into the more shallow waters near the coast, it undergoes a transformation. Since the speed of the tsunami is related to the water depth, as the depth of the water decreases, the speed of the tsunami diminishes. The change of total energy of the tsunami remains constant. Therefore, the speed of the tsunami decreases as it enters shallower water, and the height of the wave grows. Because of this "shoaling" effect, a tsunami that was imperceptible in deep water may grow to be several feet or more in height.

Figure 3-32. Tsunami Wave Characteristics.



When a tsunami finally reaches the shore, it may appear as a rapidly rising or falling tide, a series of breaking waves, or even a bore. Reefs, bays, entrances to rivers, undersea features and the slope of the beach all help to modify the tsunami as it approaches the shore. Tsunamis rarely become great, towering breaking waves. Sometimes the tsunami may break far offshore. Or it may form into a bore: a step-like wave with a steep breaking front. A bore can happen if the tsunami moves from deep water into a shallow bay or river. The water level on shore can rise many feet. In extreme cases, water level can rise to more than 50 feet (15 m) for tsunamis of distant origin, and over 100 feet (30 m) for tsunamis generated near the earthquake's epicenter. The first wave may not be the largest in the series of waves. One coastal area may see no damaging wave activity while in another area destructive waves can be large and violent. The flooding of an area can extend inland by 1000 feet (305 m) or more, covering large expanses of land with water and debris. Flooding tsunami waves tend to carry loose objects and people out to sea when they retreat. Tsunamis may reach a maximum vertical height onshore above sea level, called a runup height, of 30 meters (98 ft).

Figure 3-33. Tsunamis Impacting Hawai‘i



A tsunami's effect at the shoreline can be considerably different within very short distances. The only general rule is that runup heights tend to be greatest near where the offshore bathymetry is steeper. Along gentle-sloping coasts, wave energy is dissipated upon shoaling. Even so, inundation can be significant and is usually greatest along low-lying coastal plains. The last major Pacific wide tsunami occurred in 1964. The infrequent occurrence of Pacific-wide tsunamis in recent times makes the hazard increasingly important to understand as more and more people live and play in coastal areas. Currently, many people are not aware that tsunamis threaten many coastal areas throughout the Pacific.

Table 3-28. Tsunamis Affecting Hawaii, 1812-2002.

TSUNAMIS AFFECTING HAWAI'I, 1812-2002 (> 1 M RUNUP)										
Yr		Mo	Day	Ms	MM	Runup (m)	Runup (ft)	Runup Station Location	Source	Notes (H=Hawai'i, M=Maui, Mo=Molokai, O=O'ahu, K=Kauai'i)
1812	12/21/1812	12	21			3	10	Ho'okena, Hawai'i	S.California?	1 (H)
1819	4/12/1819	4	12			2	7	W. Hawai'I, Hawai'i	North Coast Chile	1 (H)
1837	11/7/1837	11	7			6	20	Hilo, Hawai'i	South Coast Chile	3 (H,M,O)
1841	5/17/1841	5	17			4.6	15	Hilo, Hawai'i	Kamchatka	3 (H,M,O)
1860	12/1/1860	12	1			3.6	12	Maliko, Maui	N. Pacific?	2 (M)
1868	8/13/1868	8	13			4.5	15	Hilo, Hawai'i	North Chile	6 (H.M.O,K)
1868	10/2/1868	10	2			6.1	20	Kahaualea, Hawai'i	S. Pacific?	1 (H)
1869	7/24/1869	7	24			8.2	27	Puna Coast, Hawai'i	S. Pacific?	2 (H,M)
1871	2/20/1871	2	20	7					Off Lanai?	
1872	8/23/1872	8	23			1.3	4	Hilo, Hawai'i	Aleutians	1 (H)
1877	5/10/1877	5	10			4.8	16	Wai'akea, Hawai'i	N. Chile	8 (H,M,O)
1896	6/15/1896	6	15			5.5	18	Keauhou Landing, Hawai'i	Japan	15 (H,M,K)
1868	4/2/1868	4	2	7.9	XII	13.7	45	Keauhou Landing	Ka'u	many observations
1908	9/21/1908	9	21	6.8	VI	1.2	4	Hilo, Hawai'i	Mauna Loa NE Rift	1 (H)
1919	10/2/1919	10	2	6.1		4.3	14	Ho'opuloa, Hawai'i	South Kona (landslide possibly)	3 (H), Hoopuloa submarine landslide
1926	3/20/1926	3	20			1.5			Off Wailupe, Oahu	
1951	8/21/1951	8	21	6.9	VIII	1.2	4	Ho'okena, Hawai'i	South Kona	
1952	3/17/1952	3	17	4.5	V	3	10	Kalapana, Hawai'i	Kilauea South Flank	1 (H)
1975	11/29/1975	11	29	7.2	VIII	14.3	47	Keauhou Landing, Hawai'i	Kilauea South Flank	many observations (H), 2 deaths/19 injured, **$4.1 million**;
										32 campers at foot of Pu'u Kapukapu - rocks fell pushing
										them to beach where waves started 1) 1.5 m wave,
										2) 7.9 m (26-ft)wave carried campers into crevice/ditch saving
										them from being carried to sea; subsidence 3-3.5 m (11.5ft)Halape
1901	8/9/1901	8	9	7.8		1.2	4	Ho'opuloa, Kailua-Kona, Hawai'i	Vanuatu	
1906	1/31/1906	1	31	8.1		1.8	6	Hilo, Hawai'i	Ecuador	
1906	8/17/1906	8	17	8		3.6	12	Ma'alea, Maui	Chile	
1918	9/7/1918	9	7	8		1.5	5	Hilo, Hawai'i	Kurils	
1922	11/11/1922	11	11	8.1		2.1	7	Hilo, Hawai'i	Chile	
1923	2/3/1923	2	3	8.1		6.1	20	Hilo, Hawai'i	Kamchatka	
1933	3/2/1933	3	2	8.3		3.3	11	Ka'alualu, Hawai'i	Japan	
1946	4/1/1946	4	1	7.1		16.4	54	Waikolu Valley, Moloka'i	Aleutians	159 deaths, **$26 million**, in Hilo (3800 km), 8-m waves,
										every house facing bay washed across st/smashed
1952	11/4/1952	11	4	8.2		9.1	30	Ka'ena Point, O'ahu	Kamchatka	**$0.8-1.0 million**
1957	3/9/1957	3	9	8.1		16.1	53	Kaua'i, Kaua'i	Aleutians	**$5 million**, arr Laie, Oahu (3600 km away) 12ft wave
1960	5/22/1960	5	22	8.5		10.7	35	Hilo, Hawai'i	Chile	61 deaths, **$26.5 million**
1964	3/28/1964	3	28	8.4		4.9	16	Waimea Bay, O'ahu	Alaska	
1965	2/4/1965	2	4	8.2		1.1	4	North Kaua'i, Kaua'i	Aleutians	2 observations on Kaua'l
EQ - NO TSUNAMI										
1983	11/16/1983	11	16	6.6					Kao'iki	Ext damage SE Hawai'i, **>$6 million**
1989	6/25/1989	6	25	6.1					Kalapana	SE Hawai'i, **Almost $1 million**
						covert m-ft	3.286713			

Source: International Tsunami Information Centre, 2004.

Table 3-29. Tsunami Destruction in Hawaii.

DEADLY OR DESTRUCTIVE TSUNAMIS IN HAWAI'I

DATE	SOURCE	DEATHS*	WHERE	Run-up**	REMARKS
1837	Earthquake in Chile	16	Hawaiian islands	6 m / 19.6 ft	14 deaths on the Big Island and 2 on Maui.
1868	Earthquake off the Big Island	47	Big Island	13.7 m / 45 ft	The earthquake also caused a landslide in Pahala that killed 37 bringing total deaths to 79.
1877	Earthquake in Chile	5	Hilo	4.8 m / 16 ft	Also 17 injured in Hilo.
1923	Kamchatka earthquake	1	Hilo	6.1 m / 20 ft	Others may have been killed (up to 12 others) and extensive damage occurred in Hilo and Kahului.
1933	Earthquake in Japan	1,600	Japan	3.3 m / 10.8 ft	No deaths in Hawaii but 17 feet waves were reported at Napoopoo.
1946	Earthquake in Aleutian islands	159	Mostly in Hilo (96) but also Kauai (15), Maui (14), & Oahu (9)	16.4 m / 53.8 ft	The largest natural disaster recorded to have occurred in Hawaii.
1952	Kamchatka earthquake	0	Hawaiian islands	9.1 m / 29.9 ft	Damage occurred on Kauai, Maui, Oahu, and in Hilo.
1957	Earthquake in the Aleutian islands	0	Hawaiian islands	16.12 m / 52.8 ft	Caused extensive damage on Kauai.
1960	Earthquake in Chile	61	Hawaiian islands	10.7 m / 35.1 ft	Over 1,000 people died in Chile, Japan, The Philippines, and Hawaii.
1964	Earthquake in Alaska	0	Hawaiian islands	4.9 m / 16.1 ft	106 people died in Alaska and 16 died on the North American coast. Damage occurred in Hilo and Kahului.
1975	Earthquake off the Big Island	2	Halape	14.3 m / 47 ft	19 others were injured.

* For more details see Doak C. Cox, "Tsunami Casualties and Mortality in Hawaii", University of Hawaii, Environmental Center, June 1987.

**Maximum run-up is the greatest height the tsunami was found to reach above the normal shore. The measurements listed are for the highest run-up recorded anywhere in Hawaii for that event (listed in meters and feet).

Source: International Tsunami Information Centre.

3.7.1 Tsunami Evacuation Mapping

Current tsunami evacuation maps, which were developed for the State of Hawai‘i Civil Defense and can be found in the phone books, are based on a one-dimensional inundation model and historical data. More accurate inundation maps have been proposed using a two-dimensional long-wave model. The two-dimensional model approach will provide an effective tool to numerically reconstruct five major Trans-Pacific tsunamis that have affected Hawaii within the last 100 years. This approach produces greater inundation areas in flat land locations adjacent to steep slopes, where a one-dimensional model cannot adequately describe the complex flow patterns. More accurate evacuation maps, based on the results of these two dimensional models, are considered priorities of our state-wide mitigation plan.

3.8 Volcanoes and Related Airborne Hazards

Hawaiian Volcanoes continue to be an important part of the literal and figurative landscape of our state. A symbol of the power and majesty of our island’s natural environment, the reshaping of our islands is not without significant implications for impacted communities.

Hawaiian volcanoes can either erupt at their summits or on their flanks. Young Hawaiian volcanoes, such as Kīlauea and Mauna Loa, have summit calderas. A caldera is a crater several miles in diameter that forms as the result of a collapse when magma drains from beneath the summit (Magma is the term used for molten rock that is still beneath the earth's surface; it is called lava when it reaches the surface). Summit eruptions of Kīlauea and Mauna Loa occur within or near their calderas. Flank eruptions usually take place along rift zones, which are highly fractured zones of weakness within the volcano. Rift zones typically extend from the summit of a volcano toward the coastline and may continue for many miles under the sea.

The recorded eruption history of Kīlauea that follows, demonstrates the degree of variability in eruption type, duration, and other aspects of volcanoes. Although voluminous records covering various facets of volcano activity obviously exist, it is important to note that they do not necessarily inform our mitigation strategies, as most directly impacted areas are uninhabited federal lands under the jurisdiction of the National Park Service. In turn, the brunt of the mitigation focus is on indirect impacts that have implications for population settlements.

Table 3-30. A Summary of Historical Eruptions at Kilauea from 1790 to Present.

Year	Start (mo-day)	Duration (days)	Eruptive Subdivision	Area Covered (km^2)	Volume (km^3)
1983	3-Jan	>6,200 (s)(v)	ER (u)	102	1.9
1982	25-Sep	<1	C	0.8	0.003
1982	30-Apr	<1	C	0.3	0.0005
1979	16-Nov	1	ER	0.3	0.00058
1977	13-Sep	18	ER	7.8	0.0329
1975	Nov-29 (bb)	<1	C	0.3	0.00022
1974	31-Dec	<1	SWR	7.5	0.0143 (w)
1974	19-Sep	<1	C	1	0.0102 (aa)
1974	19-Jul	3	C, ER	3.1	0.0066
1973	10-Nov	30	ER (z)	1	0.0027
1973	5-May	<1	ER (x)	0.3	0.0012 (y)
1972	3-Feb	900 (s)	ER (t)	46	0.162
1971	24-Sep	5	C, SWR	3.9	0.0077 (w)
1971	14-Aug	<1	C	3.1	0.0091
1969	24-May	874 (s)	ER (t)	50	0.185
1969	22-Feb	6	ER (r)	6	0.0161
1968	7-Oct	15	ER (q)	2.1	0.0066
1968	22-Aug	5	ER (o)	0.1	0.00013 (p)
1967	5-Nov	251	H	0.7	0.0803
1965	24-Dec	<1	ER (n)	0.6	0.00085
1965	5-Mar	10	ER (m)	7.8	0.0168
1963	5-Oct	1	ER (l)	3.4	0.0066
1963	21-Aug	2	ER (k)	0.2	0.0008
1962	7-Dec	2	ER (j)	0.1	0.00031
1961	22-Sep	3	ER (i)	0.8	0.0022
1961	10-Jul	7	H	1	0.0126
1961	3-Mar	2	H	0.3	0.00026
1961	24-Feb	1	H	0.1	0.000022 (h)
1960	13-Jan	36	ER	10.7	0.1132
1959	14-Nov	36	KI	0.6	0.0372
1955	28-Feb	88	ER	15.9	0.0876
1954	31-May	3	H, C	1.1	0.0062
1952	27-Jun	136	H	0.6	0.0467
1934	6-Sep	33	H	0.4	0.0069
1931	23-Dec	14	H	0.3	0.007
1930	19-Nov	19	H	0.2	0.0062
1929	25-Jul	4	H	0.2	0.0026
1929	20-Feb	2	H	0.2	0.0014
1927	7-Jul	13	H	0.1	0.0023 (g)

Year	Start (mo-day)	Duration (days)	Eruptive Subdivision	Area Covered (km^2)	Volume (km^3)
1924	19-Jul	11	H	0.1	0.000234
1924 (g)	10-May	17	C	No lava	No lava
1923	Aug-25 ?	1	ER	0.5	0.000073
1922	28-May	2	MC, NC	0.1	?
1921	18-Mar	7	C	2	0.0064
1919	21-Dec	221	SWR	13	0.0453
1919	7-Feb	294 (f)	C	4.2	0.0252 ?
1918	23-Feb	14	C	0.1	0.000183
1894	7-Jul	4 ?	C	?	?
1894	21-Mar	6+	C	?	?
1885	Mar	80 ?	C	?	?
1884	Jan-22 (e)	1	ER	0.1	?
1877	May-21 ?	-	K	0.1	?
1877	4-May	1 ?	CW	?	?
1868	Apr-2 ?	Short	SWR	0.1	0.000183
1868	2-Apr	Short	KI	0.2	?
1840	30-May	26	ER	17.2 (d)	0.205
1832	14-Jan	Short	east rim of C	?	?
1823	Feb-Jul	Short	SWR	10.0 (d)	0.0110 (d)
Nearly continuous lava-lake activity on the caldera floor characterized the period from before 1823 until 1924. (a)					
1790 (c)	Nov ?	-	C	No lava flow	No lava flow
1790 ?	-	-	ER	7.9	0.0275
1750 ?	-	-	ER	4.1	0.0142

Notes about the table

Eruptive Subdivisions of Kilauea Volcano

- C = summit caldera
- CW = caldera wall
- ER = east rift zone
- H = Halema`uma`u
- K = Keanakako`i
- KI = Kilauea Iki
- SWR = southwest rift zone

(a) Written records begin in July-August 1823, when the first European visited the summit of Kilauea. Thereafter until 1924, lava-lake eruptive activity was almost continuous in the caldera. Before the mid-1800s, however, records of the many overflows from the lava lake are sparse. The table lists the periods of major overflows only.

Lava flows are the most common of the direct hazards created by Hawaiian eruptions, and pose the greatest threat to property. Other hazards include airborne particles of ash, cinder, and fragile strands of volcanic glass called *Pele's* hair, and corrosive volcanic gases. Explosive eruptions occur much less often than non-explosive eruptions at Hawaiian volcanoes, but have been witnessed throughout the history of our islands. The greatest danger associated with explosive eruptions is their potential to produce pyroclastic surges. These surges are highly destructive turbulent gas clouds that flow rapidly along the ground carrying hot ash and rock fragments. A lesser volcanic hazard is created by ground movement which may result in large cracks across roads and other property, or cause uneven settling of foundations. Generally, only areas near an active or recently active volcanic vent are affected by large-scale ground cracks and settling.

3.8.1 Lava Flows

Lava flows are the most common of the direct volcanic hazards in Hawai‘i. Flows may endanger people's property, livelihood, and peace of mind, but seldom their lives. The leading edge of Hawaiian lava flows generally move more slowly than the speed at which people walk, although the lava in the channel behind the front may be flowing much faster. On steep slopes a large flow could travel rapidly enough to endanger persons in its path. During the 1950 eruption of Mauna Loa, a flow front advanced at an average speed of almost 6 mph for over 2 hours.

The speed of a lava flow is determined not only by the steepness of the terrain, but also by the volume of lava that is erupted, with larger flows advancing more rapidly. The distance that a flow travels ultimately depends both on the eruption rate and on the duration of the eruption.

The chemical composition of lava will also affect how rapidly a flow travels. Most Hawaiian lavas are classified as basalts, but this category subsumes many types. Some basalts are more fluid and will flow at greater speeds than others. The eruption of Hualalai in 1800-1801, for example, produced lava flows that appear to have been more fluid than flows from similar eruptions on Kīlauea and Mauna Loa.

The continuing eruption on Kīlauea's east rift zone, which began in 1983, provides good examples of two common, but very different, types of eruptive behavior: rapidly-moving flows produced during brief, high-volume eruptions, and slow-moving flows created by a prolonged low-volume eruption. The episodic eruptions at the Pu'u 'O'o vent, which was active from June 1983 through June 1986, produced a large volume of lava within a few hours. These outbursts were characterized by spectacular lava fountains and lava flows that moved rapidly down the volcano's south flank. The flows entered the Royal Gardens subdivision during 7 episodes and destroyed 16 homes. Each flow was short-lived, however, and stagnated soon after the lava fountains died. None of these flows reached the coastline.

In July 1986, the site of the eruption shifted to the Kupaianaha vent, 1.8 miles to the northeast of Pu'u 'O'o. Kupaianaha erupted almost continuously for over 5 years but at a much lower rate than Pu'u 'O'o. During the first few months of activity at Kupaianaha, the lava flows did not advance more than a mile beyond the vent. But after months of continuous eruption, a lava tube system formed as channeled lava flows gradually formed roofs, enclosing the rivers of lava within. Lava tubes are of significance as they have the potential to increase hazard impacts by insulating the lava and allowing it to flow much farther before cooling and stopping.

The hazards posed by a prolonged low-volume eruption soon became apparent as lava tubes from Kupaianaha extended toward the Kalapana coast. From November 1986 to October 1991, tube-fed flows repeatedly engulfed residential areas on the coastal plain, destroying 165 houses. Although these flows buried many acres within a single day, there was ample time to evacuate residents. Warnings issued by the Hawaii County Civil Defense allowed people enough time to remove most of their belongings and, in some cases, even to dismantle and move their homes. In 1992, the threat to inhabited areas eased when the eruption shifted to new vents on the southwest flank of the Pu'u 'O'o cone, inside Hawaiʻi Volcanoes National Park.

The chief threat of lava flows to property owners is that the flows may burn structures and bury land. There are other effects, however, that may be almost as disruptive, as the Kalapana community discovered during the repeated inundations of the area by lava. In addition to destroying homes, the flows covered almost 2 miles of the coastal highway. Some residents were forced to move when the highway closure increased their daily commute by nearly 100 miles. Many more residents of the Kalapana area were faced with financial losses as land values dropped and insurance companies refused to issue new homeowners policies.

Even houses that are spared by the lava, however, may be rendered uninhabitable when the roads and utility lines leading to them are destroyed. By 1996, lava flows from Kilauea's eruption had covered 8 miles of the coastal highway, isolating the few structures that remained within the area.

3.8.2 Airborne Fragments

Most volcanic eruptions produce fragments of lava that are airborne for at least a short time before being deposited on the ground. These fragments are called "tephra," and include ash, cinders, and Pele's hair. In Hawaii, tephra is usually ejected by lava fountains and poses a serious hazard only in the immediate vicinity of an erupting vent. Windborne tephra, however, can be disruptive at greater distances. The combination of high lava fountains and strong winds may result in tephra being carried many miles downwind of the eruption site. During lava fountaining episodes at Pu'u 'O'o from 1984 to 1986, the prevailing trade winds deposited most of the tephra in remote areas of Hawaii Volcanoes National Park, but small particles reached the town of Naalehu 39 miles away. During the same episodes, Kona winds (from the southwest) occasionally carried tephra to Hilo, 22 miles from the vent.

The small amount of tephra that fell on inhabited areas was not harmful to most people, but it was a source of irritation to those with respiratory problems and an inconvenience to the many residents with rain-water-catchment systems. Following at least three high-fountaining episodes, Hawaii County Civil Defense recommended that people disconnect and clean their rain-water catchment systems to prevent the particles from washing into their water supply.

3.8.3 Volcanic Gases

Volcanic gases are emitted during all types of eruptions. Gases can also be released during repose periods by inactive eruptive vents and by fumaroles, vents that may never have produced any lava. The gas plume rising from an active vent on Kīlauea consists of about 80 percent water vapor with lesser amounts of sulfur dioxide, carbon dioxide, and hydrogen. Small quantities (typically less than 1 percent by volume) of carbon monoxide, hydrogen sulfide, and hydrogen fluoride are also present. Extremely small amounts of mercury and other metals have been detected in gases emitted from vents along the east rift zone of Kīlauea, but none have been found in concentrations large enough to create a direct health hazard.

Any hazard posed by volcanic gases is greatest immediately downwind from active vents; the concentration of the gases quickly diminishes as the gases mix with air and are carried by winds away from the source. Brief exposure to gases near vents generally does not harm healthy people, but it can endanger those with heart and respiratory ailments, such as chronic asthma.

Eruption gases containing high levels of fluoride are also recognized as a threat to livestock in communities downwind of Mauna Loa and Kīlauea. Although rare in Hawai‘i, anecdotal reports of livestock losses in downwind areas of Kīlauea have been recorded.

A common gas produced during Hawaiian eruptions that is potentially harmful to human health is sulfur dioxide. Even small concentrations of sulfur dioxide can combine with water to form sulfuric acid, which can attack skin, cloth, metal, and other materials. When a volcanic plume mixes with atmospheric moisture, acid rain results. Acid rain can significantly retard the growth of cultivated or natural plant life downwind of a vent that degasses over a long period of time.

The sulfur dioxide emitted from Kīlauea's summit during typical non-eruptive periods affects a relatively small area downwind of the summit. Similarly, the gases produced during short-lived eruptions affect only a limited area, although their odor may be detected many miles from the vent. The continuous emission of volcanic fumes during Kīlauea's Pu'u 'O'o-Kupaianaha eruption, however, resulted in persistent volcanic haze and acid-rain conditions in the South Kona district on the leeward side of the island.

In late 1987, studies conducted on private water-catchment systems in the South Kona area revealed higher than average acidity in several water samples. Drinking the acidic water does not pose a health hazard, but such water can leach lead from the lead roof flashings, lead-headed nails, and solder connections found in many plumbing systems, resulting in unsafe levels of lead in the drinking water. Extensive testing in 1988 determined that many water-catchment systems on the island, particularly those in the districts adjacent to or downwind of the active vent, contained elevated levels of lead. Residents with rain-catchment systems should contact the Hawaii State Department of Health for information on how to avoid lead contamination of their drinking water.

Volcanic fumes can also damage agricultural crops. During the 1969-74 eruption of Kilauea's Mauna Ulu vent, the South Kona district experienced prolonged periods of eruption-related smog. A study conducted in 1972 by the University of Hawaiʻi's Agricultural Experiment Station at Hilo concluded that the acid rain resulting from the fumes was responsible for severe damage to the Kona tomato crop. The Pu'u 'O'o-Kupaianaha eruption of Kīlauea caused similar problems for vegetable and flower growers in both the Kona and Puna districts, who reported light-to-moderate crop damage during periods when winds blew the gases over their fields.

3.8.4 Explosive Eruptions

The rare explosive eruptions in Hawaii are generally caused by the interaction of magma and ground water. The magnitude of the resulting steam explosion varies from harmless to catastrophic. Small steam-blast explosions occurred during the 1960 Kapoho eruption when the magma beneath the vents, which were near sea level, encountered saltwater trapped in the surrounding rocks. These steam blasts ejected black clouds of pulverized rock fragments but were of little hazard except to scientists working close to the vents.

A much larger steam-blast eruption occurred at the summit of Kilauea in 1924, when ground water apparently flowed into the heated rocks beneath the Halemaumau vent, which had been erupting nearly continuously for over a century. The explosions continued at intervals for 2 weeks, carpeting the area around Halemaumau crater with large rocks and a thin layer of ash. Boulders weighing several tons were thrown as far as 3,000 feet from the crater. The greatest hazard posed by this type of activity is that it may start abruptly and endanger unwary onlookers. The 1924 eruption claimed one fatality--a man who ventured too close to the vent between explosions to take photographs and was struck by a rock when the activity suddenly resumed.

The largest explosive eruption on Hawaiʻi within recorded history occurred in 1790. This eruption produced pyroclastic surges (turbulent clouds of hot gas and rock fragments) that originated at Kilauea's summit and flowed several miles to the southwest. Pyroclastic surges are extremely dangerous because they move at speeds of 30 to 200 mph, and humans and animals caught in their path are killed by either asphyxiation or heat. A band of Hawaiian warriors traveling from Hilo to the Ka'u district to battle with Chief Kamehameha were overtaken by one of the 1790 pyroclastic surges, and about 80 of them were killed. The 1790 eruption left deposits of rock fragments and ash up to 30 feet thick on the rim of Kilauea's summit caldera.

The thick deposits of ash exposed at many sites on the island indicate that even larger explosive eruptions occurred in prehistoric times and probably originated from Mauna Kea as well as from Kilauea. Explosive eruptions of any size take place infrequently in Hawaii, but the possibility of one occurring in our lifetime should not be totally discounted. However, such eruptions are unlikely to begin without some warning. The most widespread hazard from an explosive eruption would be windborne ash, which could damage structures, machinery, and agricultural crops.

3.8.5 Ground Cracks and Settling

Ground cracks and settling are commonly associated with volcanic activity; both generally occur near active or recently active volcanic vents as the result of shallow underground movement of magma. The beginning of an eruption at a new site is preceded by cracking of the ground as magma is forcefully injected into the area. The cracks may be as much as 6 feet wide and over a mile long; typically they form within a period of hours. The Kapoho area on Kilauea's lower east rift zone experienced such ground breakage prior to eruptions in 1924, 1955, and 1960.

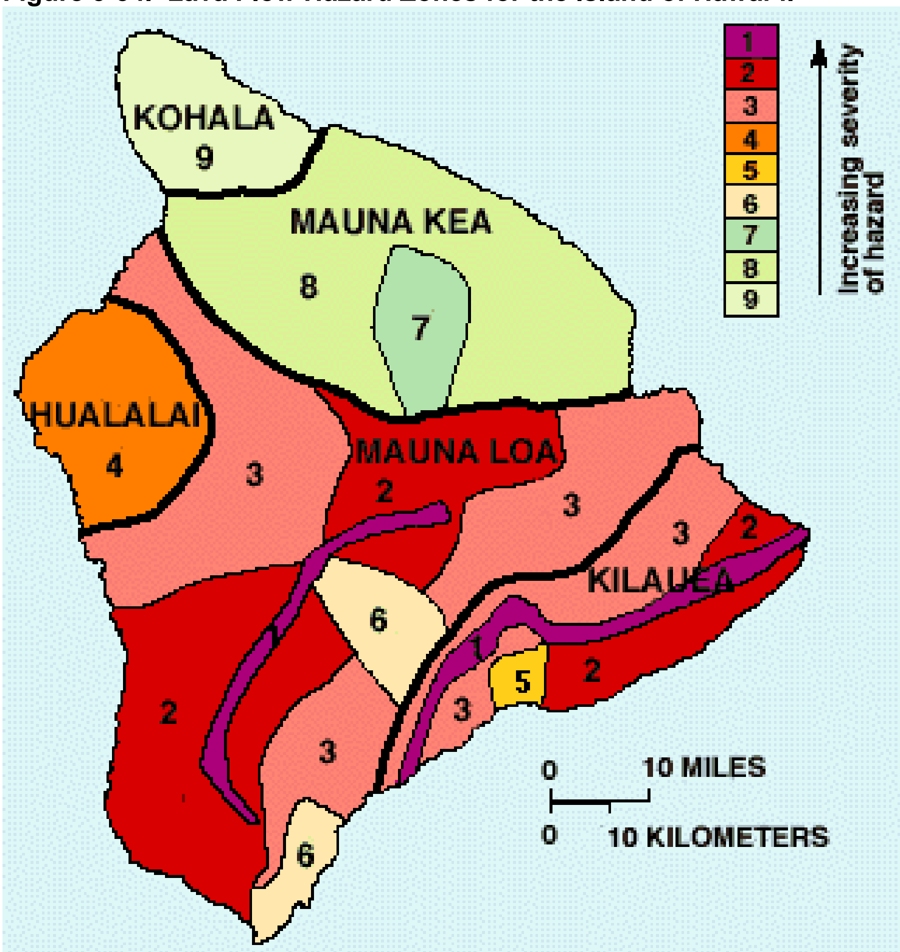
Ground settling may occur near a vent at the end of an eruption as magma drains away from beneath the vent area. This process produces both small depressions and large collapse features, such as the pit craters and summit calderas of Kilauea and Mauna Loa. In either case, the subsidence may be gradual or abrupt.

The hazard presented by ground cracks and settling associated with eruptions is usually limited to areas near the active vent and thus is overshadowed by the hazard posed by lava flows. Man-made structures that escape other damage from an eruption, however, can be damaged or destroyed by cracking, tilting, or settling of the ground beneath them. Ground cracks will remain after the eruption is over and can pose a threat to unwary people and animals if the cracks are obscured by heavy vegetation.

3.8.6 Lava Flow Hazard Zones

Hazard zones from lava flows are based chiefly on the location and frequency of historic and prehistoric eruptions and the topography of the volcanoes. Scientists have prepared a map that divides the five volcanoes of the Island of Hawai`i into zones that are ranked from 1 through 9 based on the relative likelihood of coverage by lava flows.

Figure 3-34. Lava Flow Hazard Zones for the Island of Hawai`i.



Hazard zone boundaries are approximate. The change in the degree of hazard from one zone to the next is generally gradual rather than abrupt, and the change can occur over the distance of a mile or more. Within a single hazard zone, the severity of hazard may vary on a scale too fine to map. These variations may be the result of gradual changes that extend across the entire zone. For example, the hazard posed by lava flows decreases gradually as the distance from vents increases.

There may be abrupt changes, however, in the relative hazard because of the local topography. For example, the hills behind Ninole stand high above the adjacent slopes of Mauna Loa and consequently are at a much lower risk from lava flows than the surrounding area, even though the entire area is included in a single zone. To determine the hazard differences within a single zone, more detailed studies are required.

Table 3-35. Hazard Zones for Lava Flows on the Island of Hawai‘i.

HAZARD ZONES FOR LAVA FLOWS			
Zone	**Percentage of area covered by lava since 1800**	**Percentage of area covered by lava in last 750 years**	**Explanation**
1	greater than 25	greater than 65	Includes the summits and rift zones of Kilauea and Mauna Loa where vents have been repeatedly active in historic time.
2	15-25	25-75	Areas adjacent to and downslope of active rift zones.
3	1-5	15-75	Areas gradationally less hazardous than Zone 2 because of greater distance from recently active vents and/or because the topography makes it less likely that flows will cover these areas.
4	about 5	less than 15	Includes all of Hualalai, where the frequency of eruptions is lower than on Kilauea and Mauna Loa. Flows typically cover large areas.
5	none	about 50	Areas currently protected from lava flows by the topography of the volcano.
6	none	very little	Same as Zone 5.
7	none	none	20 percent of this area covered by lava in the last 10,000 yrs.
8	none	none	Only a few percent of this area covered in the past 10,000 yrs.
9	none	none	No eruption in this area for the past 60,000 yrs.

3.9 Coastal Erosion

The beaches of Hawaiʻi are vital economic, environmental, and cultural resources. A healthy, wide sandy beach provides protection against the effects of storm surge, tsunami flooding, and high surf impacts. The beach environment provides habitat for marine and terrestrial organisms with beach dependent life stages and is home to species of indigenous and endemic Hawaiian plants. Beaches are also the basis for the visitor industry, exceeding by a factor of three all other industries combined when providing direct income to the State (DLNR, Coastal Erosion Management Plan, 2000). In addition, the beaches of Hawaiʻi are a public trust resource, whose protection is required by State Statutes and case law.

Beaches change their shape, depth, and slope in response to wind, wave, and current forces, and the availability of sand. The sources and sinks of sand within a particular beach system and the mechanisms by which they affect the beach morphology are often cumulatively referred to as the sediment budget of the beach. Seaward sources of sand to the sediment budget of a beach include longshore currents moving sand along the coast and cross-shore currents moving sand onshore. Landward sources of beach sand include dunes, ancient shorelines, and other onshore sand deposits that release sand to the beach by the forces of the wind and waves. High waves will cause a beach to change its shape, or profile by redistributing sand across the shoreline.

Causes of coastal erosion and beach loss in Hawaii are numerous but, unfortunately, are poorly understood by the public and rarely quantified. Construction of shoreline hardening structures limits coastal land loss but does not alleviate beach loss and may actually accelerate the problem by prohibiting sediment deposition in front of the structures. Other factors contributing to beach loss include reduced sediment supply, large storms, and sea-level rise.

Reduction in sand supply, either from landward or seaward (primarily reef) sources, can result from a number of factors. Obvious threats, such as beach sand mining and structures that prevent natural movement of beach deposits, remove sediment from the active littoral system. More complex issues of sediment supply can be related to reef health and carbonate production, which in turn, may be linked to changes in water quality. In addition, the accumulated effect of large storms will be the transportation of sediment beyond the littoral system. Rising sea level leads to a landward migration of the shoreline. Dramatic examples of coastal erosion, such as houses and roads falling into the sea, are rare in Hawaii, but the impact of erosion is still very serious.

The signs of erosion in Hawaiʻi are much more subtle and typically start as a "temporary" hardening structure designed to mitigate an immediate problem which, eventually, results in a proliferation of structures along a stretch of coast. The natural ability of the sandy shoreline to respond to changes in wave climate is lost. The erosion problem in Hawai‘i should be addressed through coastal construction setback rules (discussed in Chapters 6 and 7).

Coastal zones are dynamic areas that are constantly undergoing change in response to a multitude of factors including sea level rise, wave and current patterns, hurricanes, and human influences. Despite the fact that Hawaii appears to be developing a comprehensive governmental system in place to respond to coastal erosion and beach loss, beach loss is occurring more frequently and most governmental agencies are not equipped to deal with this state-wide chronic hazard since it is so pervasive and politically sensitive.

High winds and associated marine flooding from storm events such as Kona Storms and hurricanes, sea level rise, seasonal high surf, stream flooding on coastal plains, all increase the risk exposure along developed coastal lands. Coastal erosion and beach loss are chronic and widespread problems in the Hawaiian Islands. Typical erosion rates in Hawaii are in the range of 15-30 cm/yr or 0.5-1 ft/yr, with some areas reaching annual average erosion rates of up to 5-6 ft /yr (Hwang, 1981; Sea Engineering, Inc., 1988; Makai Engineering, Inc. and Sea Engineering, Inc., 1991).

Beach erosion and coastal erosion are not the same, but they are related. Beach erosion is a reduction in the amount of sand a particular beach has. On a global level, sea level rise causes beach erosion. But beaches also erode (and expand) on a seasonal basis.

Seasonal (episodic) erosion- consists of temporary erosion that is a function of a single event or a series of seasonal events but eventually the beach recovers.

Chronic (ongoing) erosion- The ongoing and pervasive erosion of the beach and coast with little to no recovery. Over the long-term most coasts in Hawaii are experiencing chronic erosion.

Beaches get sand from both the ocean and the land. Larger waves move sand from the coastal sand dunes off into the ocean. This raises the seafloor and flattens the overall profile of the beach, causing waves to break further offshore. This, in turn, minimizes the waves' impact on coastal lands. Beaches recover from these seasonal shifts when the waves move the sand back onto the beach and the winds blow the deposited sand into dunes. These dunes store the land-based sand until the next large wave event.

Coastal erosion occurs when the beach migrates toward the land in order to compensate for beach erosion as it tries to maintain a constant supply of sand. Under chronic erosion conditions when sand is not available to a beach, such as when a wall is built to protect the land, the land is stabilized, however beach erosion may still occur.

Installing a seawall or revetment (i.e., hardening a shoreline) interferes with the natural cycle of beach erosion. Rather than pulling sand from a landward supply in order to promote waves breaking further off-shore during the seasonal high wave period, the seawall or revetment prevents these natural phenomena from occurring. Thus, the land itself begins to erode. In many cases seawalls or revetments have been installed to prevent coastal erosion, but their very presence exacerbates the very problem they were supposed to resolve.

Erosion is caused by: 1) Human impacts to sand availability; 2) Waves and currents moving sand; and, 3) Sea-level rise forcing shoreline retreat.

3.9.1 Impoundment

Coastal lands such as inland dunes and sandy plains are typically composed of carbonate sand in Hawaii; therefore, when they experience chronic erosion and the shoreline shifts landward, a supply of sand is released to the adjoining beach and near-shore region. The beach then remains wide even as it moves landward with the eroding shoreline.

Most beach sand in Hawaii is composed of carbonate grains derived from the skeletons of corals, mollusks, algae, and other reef-dwelling, carbonate-producing organisms. Sand supplies are limited relative to mainland coasts where terrigenous sand derived from large rivers and other sources dominate. The formation of beachrock, storage of sand in coastal dunes, and irretrievable sand loss to deeper water beyond the reef crest all contribute to relatively low volumes of sand available to the system. On many Hawaiian beaches, the available sand ends beyond the toe of the beach in a water depth of 1.2-1.8 m (4-6 ft) where the bottom becomes reef or a reef pavement. In contrast, on mainland beaches the sand deposits often extend a considerable distance (hundreds to thousands of meters) offshore.

Sediment impoundment often accompanies coastal armoring. Sands that would normally be released into coastal waters during high wave events and with seasonal profile fluctuations are trapped behind walls and revetments and prevented from adding to the beach sediment budget. One wall may have minimal impact, but along many Hawaiian coastlines myriad armoring types have the cumulative effect of damaging the beach, an erosion prone area, by reducing sand availability to nearly zero. Natural coastal erosion does not damage beaches that have access to a robust sediment budget. Armoring traps those sands and a sediment deficiency develops, such that the beach does not withstand seasonal wave stresses and begins to narrow with time
In Hawaii, coastal erosion issues are addressed by three layers of jurisdiction with varying degrees of overlap and coordination: The Army Corps of Engineers; the State Coastal Zone Management Program and Department of Land and Natural Resources, and County Government. Federal jurisdiction applies to the navigable waters of the United States, extending from the mean high water mark to the 200-mile limit of the Exclusive Economic Zone. State jurisdiction is the conservation district, which extends from the certified shoreline (often the vegetation line) to the limit of state territorial waters. County jurisdiction extends landward from the certified shoreline to the limit of the special management area boundary, which varies in width from a couple hundred yards to a few miles.

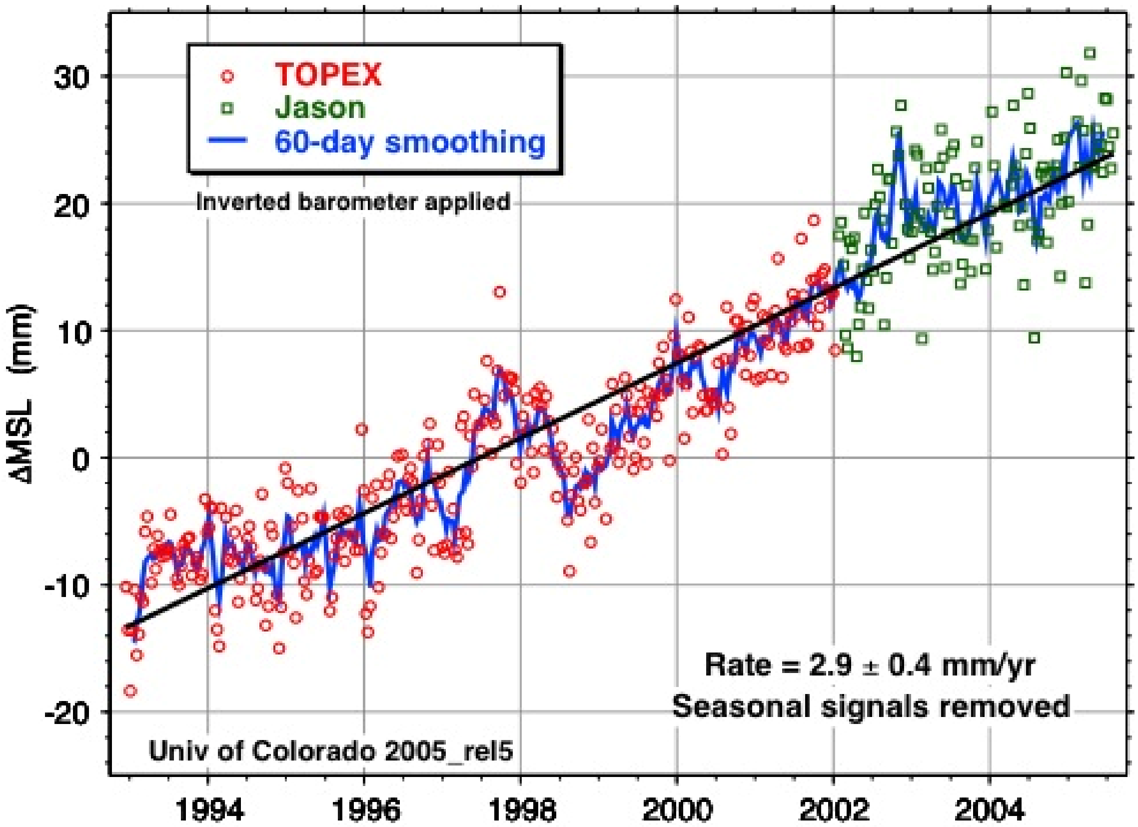
This “mixed” jurisidiction is the source of Hawaii’s complex and inefficient coastal regulatory system. Often one agency’s policies (i.e. infrastructure protection) may be at odds with another agencies policies (i.e. resource protection). Historically, the protection of private property and public infrastructure has outweighed the protection of the natural resource (beaches).

3.9.2 Sea Level

Hawai‘i has a system of tide gauges, maintained and operated by the federal National Ocean Service, located on the islands of Kaua‘i, O‘ahu, Maui, and Hawai‘i that record fluctuations in sea-level. Analysis of these records provides scientists with rates of long-term sea-level rise around the state. A fascinating outcome of this has been the realization that each island has its own rate of rising sea level. This is not because of ocean behavior, it is due to island behavior. The Island of Hawai‘i, because of the heavy load of geologically young volcanic rocks, is flexing the underlying lithosphere causing the island to subside. This creates a relatively rapid rate of sea-level rise, on the order of 1.5 in/decade. Because it lies near the Island of Hawai‘i and is also geologically youthful, Maui is affected by the flexure process and is experiencing rapid sea-level rise, nearly 1 in/decade. O‘ahu and Kaua‘i lie outside the area of subsidence and have lesser rates of rise, approximately 0.6 in/decade.

Recent satellite measurements indicate global mean sea level rise is 3.0 mm/yr which is almost 2 times the rate of the last century. (See http://sealevel.colorado.edu/, Steve Nerems site at Boulder.) Since August 1992, the satellite altimeters have been measuring sea level on a global basis with unprecedented accuracy. The TOPEX/POSEIDON (T/P) satellite mission provided observations of sea level change from 1992 until 2005. Jason-1, launched in late 2001 as the successor to T/P, continues this record by providing an estimate of global mean sea level every 10 days with an uncertainty of 3-4 mm. The latest mean sea level time series and maps of regional sea level change can be found on this site. Concurrent tide gauge calibrations are used to estimate altimeter drift. Sea level measurements for specific locations can be obtained from our Interactive Wizard. Details on how these results are computed can be found in attached documentation and the bibliography.

Figure 3-35. Sea Level Change and Acceleration.



Church, J. A. and N. J. White., 2006: A 20th century acceleration in global sea-level rise, *Geophys. Res. Lett.*, **33**(1), L01602.

Sea-level rise is not presently a cause for immediate alarm, although it may present a serious hazard in the future. Questions regarding future rates of rise resulting from an enhanced greenhouse effect have been discussed by scientists, planners, and policymakers throughout the 1980's and 1990's. At present, sea level is projected to rise 2 ft over the 21st century. This is more than twice the rate of rise of the 1900's. Other researchers predict sea level rise could be 1-2 meters of more this century. The impact of rising sea level in the Hawaiian Islands will be severe unless planners and resource managers incorporate sea-level rise scenarios into their coastal management efforts. As sea-level rise accelerates in the future, low-lying, low relief, readily erodible, and low slope coasts will be the most vulnerable to sea-level hazards. (A more complete discussion of future sea levels and impacts is available in Fletcher 1992 and the IPCC Working Group 1 and 2 reports from the Fourth Assessment 2007, www.ipcc.ch.)

Present rates of sea-level rise play a role in coastal retreat. The engineers' "Bruun Rule" (relating sea-level rise to beach retreat (Bruun 1962) predicts a retreat of 4-5 ft/decade on O'ahu (Hwang and Fletcher, 1992). This finding is supported by aerial photographic measurements of beach retreat and suggests that presently narrow beaches fronting seawalls on these islands are likely to be lost over the next quarter century. Hwang (2003) has recommended an Erosion Zone Formula that consists of three major factors: the trend risk, the storm erosion event, and a design safety buffer.

Erosion Zone = Trend Risk + Storm Erosion Event + Design Safety Buffer

The Trend Risk is determined by multiplying the planning lifetime of buildings times the erosion rate. The erosion rate is adjusted for errors (FEMA CCM, 2000) and sea level rise.

Trend Risk = (Life Expectancy of Structures) x (Erosion Rate x Adjustment for Errors x Adjustment for Accelerated Sea Level Rise)

Thus, the parameters needed to determine the erosion zone are:

- Planning Period – Determined by Life Expectancy of Structures
- Average Annual Erosion Rate
- Adjustment of Erosion Rate for Errors
- Adjustment of Erosion Rate for Accelerated Sea Level Rise
- Storm Erosion Event
- Design Safety Buffer

Table 3-32. Extent of Erosion Zone Given Erosion Rate and Life Expectancy.

Erosion Rate ft./yr.	Adjusted Rate for Errors (20%)	Adjusted Rate for Errors and Accelerated Sea Level Rise (20%) x (10%)	Storm Event	Safety / Design Buffer	Erosion Zone 70-yr. Life of Structure	Erosion Zone 50-yr. Life of Structure
0	0.12	.013	20	20	49	35
.1	0.12	.013	20	20	19	35
.2	0.24	0.26	20	20	58	41
.3	0.36	0.39	20	20	67	48
.4	0.48	0.52	20	20	76	54
.5	0.60	0.66	20	20	86	61
1.0	1.20	1.32	20	20	132	94
1.5	1.80	1.98	20	20	179	128

For areas that are accreting, the erosion rate should be treated as zero, since HRS Section 183-45 prohibits building structures on accreted land. For areas with an erosion rate of 0, the setback is based on an erosion rate of 0.1 ft./yr. Factors related to the accelerated sea level rise adjustment or the storm event of 20 feet may be analyzed by a consultant to determine if a different number is warranted for a specific site. This analysis assumes no adjustments for erosion rate variability.

For O‘ahu, there is a 60-foot setback for new subdivisions. This would be comparable to the setback for structures with a 50-year life and an average erosion rate of 0.5 ft./yr

(5 feet per decade). However, the fixed 60-foot setback would be too small if the measured erosion rate increases or for a longer building lifespan. For example, if the erosion rate is 0.5 ft./yr., the setback for a 70-year structural lifespan should be about 86 feet. Additionally, ordinances that allow renovation of structures within their existing footprints substantially lengthen the lifetime of the land use. Maui differs in that it uses a rate equal to 50 times the annual ave erosion rate (see the Maui County plans at http://www.co.maui.hi.us/departments/Planning/czmp/ssa.htm).

The FEMA CCM recommends that for the building lifetime, a minimum of 50 years be utilized. The 70-year extended time frame recommended by Hwang is based on a study conducted for the Federal Insurance Administration, Department of Housing and Urban Development to establish reliable estimates for the life of coastal residential structures (Anderson 1978).

Figure 3-36. Sea Level Rise in Hawai'i.

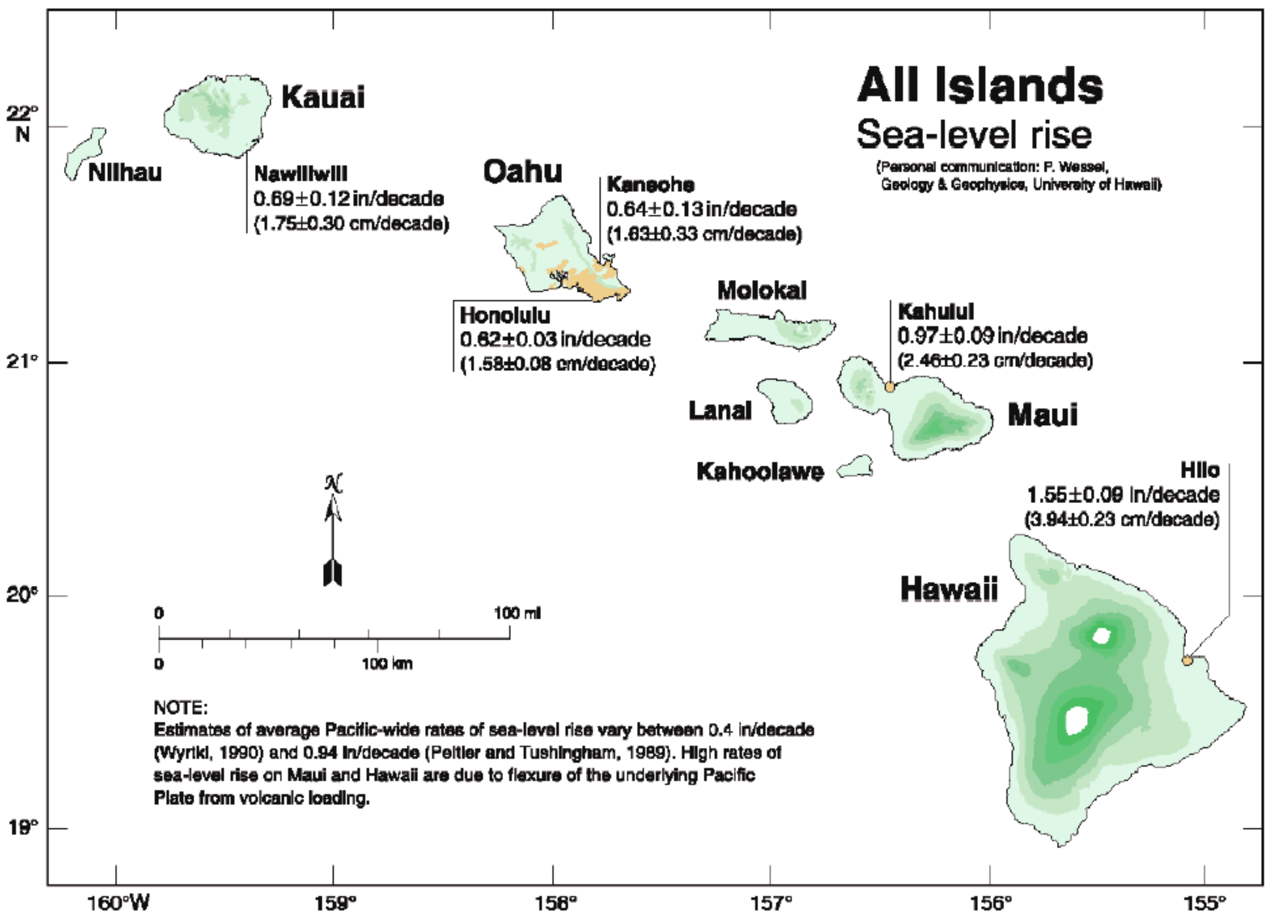


Table 3-33. Hazard Intensity Rank Definitions.

Hazard	Low (1)	Moderately Low (2)	Moderately High (3)	High (4)
Erosion	long-term accretion (>10 yr) with no history of erosion, or dynamic cycles with consistent annual accretion	long-term stable or minor erosion / accretion cycles with erosion fully recovered by accretion; low rocky coasts; perched beaches	long-term erosion rate <1 ft/yr or highly dynamic erosion / accretion cycles with significant lateral shifts in the shoreline	chronic long-term erosion >1 ft/yr, or beach is lost, or seawall at water-line for portions of the tidal cycle
Sea Level (0.04 in=1mm)	steep coastal slope where rise >0.04 in/yr or gentle slope where rise <0.04 in/yr	gentle or moderate slope, where rise >0.04 in/yr or steep slope where rise >0.08 in/yr	gentle or moderate slope, where rise >0.08/yr or steep slope where rise >0.12 in/yr	gentle or moderate slope, where rise >0.12 in/yr

Table 3-34. Beach. Narrowing and Loss on O'ahu.
(Adapted from Coyne, et. al., 1996 and Fletcher, et. al., 1997.)

Beach Condition and Change	Mokuleia	Kaaawa	Kailua-Waimanalo	Maili-Makaha	Island-wide
Originally sandy (km)	12.2 +/- 1.0	7.5 +/- 0.6	15.5 +/- 1.3	6.0 +/- 0.5	115.6 +/- 9.8
Narrowed beach (km)	2.1 +/- 0.2	3.2 +/- 0.3	0.9 +/- 0.1	1.3 +/- 0.1	17.3 +/- 1.5
Lost beach (km)	0.2 +/- 0	0.8 +/- 0.1	1.6 +/- 0.1	0.2 +/- 0	10.4 +/- 0.9
Degraded beach (%)	18.7	53.6	16.3	24.9	23.9
Net shoreline change rate (m/yr)	-0.2 to 0.3	-1.7 to 1.8	-0.9 to 0.6	-0.4 to 0.6	N.C.
Non-armored mean sandy beach width (m)	26.8	13.2	22.4	43.7	N.C.
Armored mean sandy beach width (m)	12.8	8.9	7.1	24.5	N.C.
Mean long-term shoreline change rate for armored sites (m/yr)	-0.2	-0.3	-0.6	-0.5	N.C.
Range of shoreline change rates for armored sites (m/yr)	-0.1 to -0.3	0 to -1.7	0.2 to -1.8	-0.2 to -1.0	N.C.

As of 1991, O'ahu has lost 6.4 miles of beach and has had narrowing of 10.7 miles due to shoreline hardening (*i.e.*, seawalls and revetments). This was approximately 24% of O'ahu's sandy shoreline (originally 71.6 miles) (O'ahu Shoreline Management Plan-Sea Engineering, Inc., 1991). Numerous shoreline structures have been permitted, or erected without permits in the interval since the report was written. Many of the beaches of O'ahu, which have a high public value as a natural resource and are limited in extent, are being destroyed through erosion. Some of the loss is from natural causes, such as waves wind and severe storms, but much of it is associated with man-made developments (see the 1991 O'ahu Shoreline Management Plan,Sea Engineering, Inc)." Additionally, sea-level rise for Oahu is reported at 0.6 in/decade (1.57 $\pm$ 0.08 mm/yr).

3.9.3 Erosion Risks for Maui County

Maui's sandy beaches are disappearing as a result of natural shoreline processes, development and hardening along the shoreline, and other human impacts. Reportedly, 5 miles of beach loss (12%), and 20% average beach width decrease has occurred on Maui. Sea-level rise, currently averaging about 2.5 cm/decade on Maui, also causes coastal erosion. Examination of a report on shoreline changes from 1949 to 1989 suggests that 62% of the sandy shoreline studied on Maui is eroding at an average rate of 1.25 ft/yr (Hwang and Fletcher, 1992), and as much as 30% of Maui's shoreline has experienced beach loss or significant narrowing (Makai Ocean Engineering, Inc. and Sea Engineering, Inc., 1991). Based on field and photographic observations, nearly all of this beach degradation is in front of or adjacent to shoreline armoring such as seawalls and revetments. The risks for erosion appear on the coastal hazard maps, attached in Chapter 3, Appendix 1. Recognizing the importance of Maui's beach resources, it is imperative that they be preserved, protected and restored where possible.

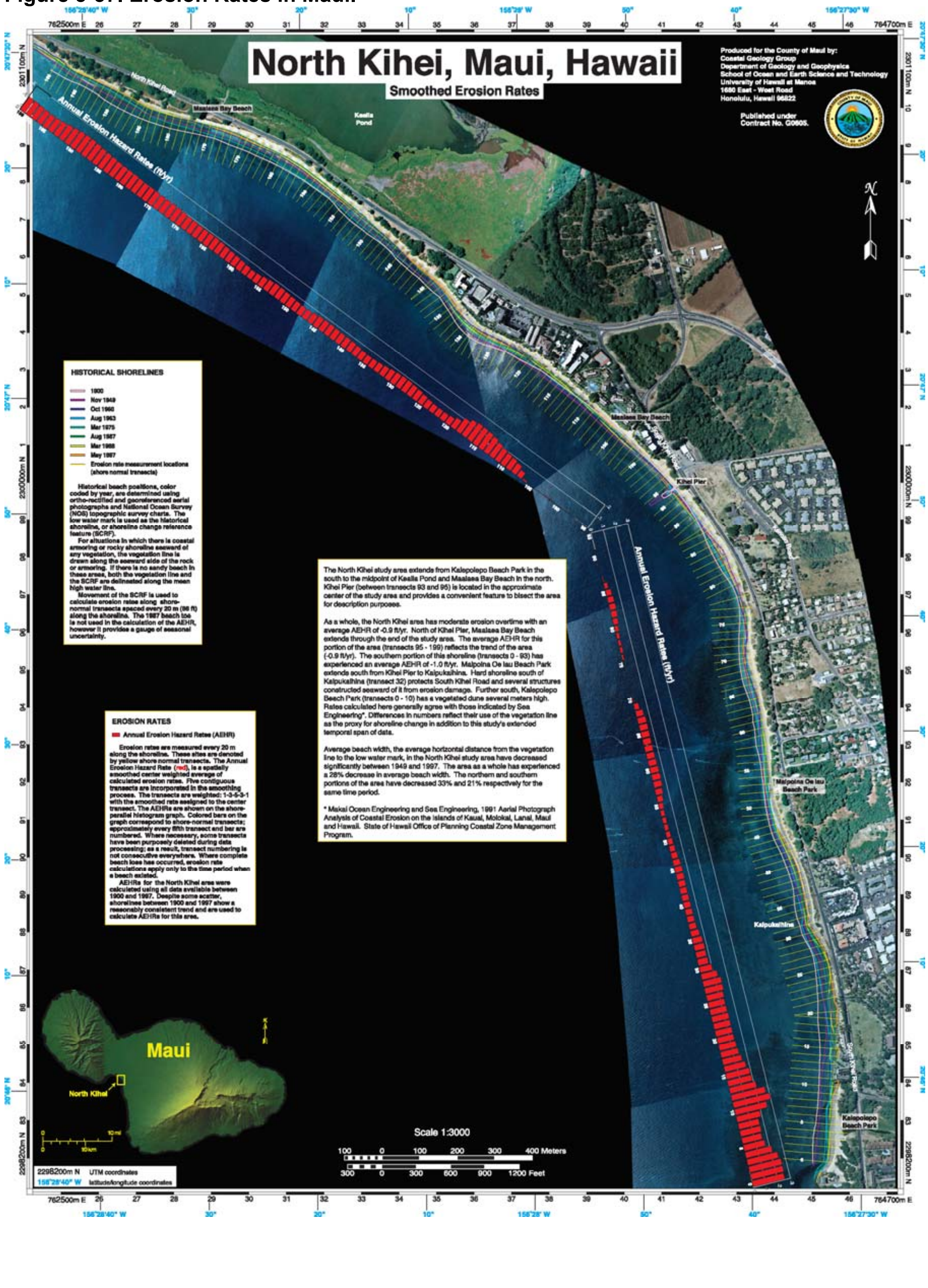
In many respects, the Maui County administration has emerged as the local leader of beach erosion management in Hawai'i with the publication and implementation of the Maui County Beach Management Plan. Issues discussed in this plan include: 1) where and why coastal erosion and beach loss have occurred, and 2) recommendations for more effective management of shoreline areas and the development of increased options for resource conservation and erosion mitigation. Shoreline processes are the net result of many interrelated systems. Effective management of shoreline resources requires input from several different fields of study. Some progress has been made in Maui County and the State of Hawai'i to reduce the impact of activities on coastal erosion. For example, large-scale sand mining was prohibited in 1986. In 2000, the Maui County Planning Department revised the shoreline setback rules to require some building setbacks to be based on average lot depth. Other counties have beach management plans that have never been implemented: Kauai 1991 and Oahu 1990.

Table 3-35. Preliminary Erosion Hotspots, Watchspots, and Lost Beaches for Maui.

LOCATION	HOTSPOTS	WATCHSPOTS	LOST BEACHES
WEST MAUI	North end of Puuoa Point	Hanakaoo Point	Lahaina Town
LAHAINA TO NAPILI	Hyatt Regency	Maui Surf (Westin)	Wahikuli State Wayside Park
	Portions of Kaanapali Beach	Ends of Kekaa (North Beach)	Either side of Honokowai Beach Park
	Mahana Condominium	Mala Wharf area	Either side of Kahana Point
	Honokowai Beach		Honokeana Cove
	Honokowai Point		
	Honokowai Beach Park		
	Kahana Point		
	Kahana Sunset (Keonenui Beach)		
	Alaeloa Beach		
	Napili Bay		
	Kapalua Bay (shower, steps and sidewalks threatened)		
SOUTH MAUI I	East end of Hauoli Street, Maalaea	Maui Lu to Suda's Store	West end of Hauoli Street, Maalaea
MAALAEA TO KALAMA	Kealia Beach hotspot areas		Koa Lagoon, Maui Lu area
	Maipoina Oe Iau Beach Park		Menehune Shores
	Maui Sands		South end of Halama Street - Waimahaihai
	Hale Kai O Kihei - end of Lipoa St.		Kalama Beach Park
	Central Part of Halama Street		
SOUTH MAUI II	Hale Hui Kai Hotel - No. Keawekapu	Mokapu Beach	none
KAMAOLE TO MAKENA	South Keawekapu Beach	Polo Beach	
	Ulua Beach	Palauea Beach	
NORTH SHORE	Hobron Point to Kaa	Baldwin Beach Park	Wailuku/Kahului Wastewater Reclamation Facilities
KAHULUI HARBOR	Kaa to Kanaha Beach Park	Mantokuji Bay	
TO KUAU	Most of Kanaha Beach Park		Portions of Stable Road Beach
	Spreckelsville Beach		Baldwin Beach Park lime kiln
	Most of Stable Road Beach		Portions of Kuau Bay
	Sugar Cove (lost, but replenished)		Portions of Tavares Bay
	East end of Lower Paia Bay		

The University of Hawai'i School of Ocean, Earth Science and Technology (SOEST) Coastal Geology Group has developed the Maui shoreline change website, which provides a historical shoreline database for the Kihei coast, Northwest Coast, and North Shore of Maui (Zoe Norcross, Maui Sea Grant Extension Agent, SOEST, http://www.soest.hawaii.edu/coasts/ and http://www.co.maui.hi.us/departments/Planning/erosion.htm.)

Figure 3-37. Erosion Rates in Maui.



3.9.5 Erosion Risks for Kaua‘i County

The risk for erosion appears on the coastal hazard maps, attached in Chapter 3 Appendix 1. These maps show general coastal hazard risks for segments of the coastline every five to seven miles. On Kaua‘i, short sections of populated coast have undergone extensive hardening and chronic erosion. As much as one to two miles of beach degradation has occurred there. Intensive studies to record shoreline erosion, are being conducted for O‘ahu and Kaua‘i. However, a few incidents related to erosion and seawall conflict have occurred with respect to building seawalls for protection, despite recent studies demonstrating that hardening results in increased problems along the shoreline. One example is the Waialua Golf Course, a PGA rated course where one hole of the course is eroding. Sea-level rise for Kaua‘i is reported at 0.7 in/decade (1.75± 0.32 mm/yr) (http://www.soest.hawaii.edu/coasts.htm).

3.9.6 Erosion risks for Hawai‘i County

Overall the Island of Hawai‘i has a moderately low erosion threat. Strong waves along the Northshore of Hawai‘i affect low-lying coastal embayments of Waipi‘o and Waimanu increasing the erosion hazard to moderately high (C. Fletcher et al., Atlas of Natural Hazards in the Hawaiian Coastal Zone). Hawai‘i’s erosion is more related to bluff erosion and bench collapse which occurs more episodically and is hard to measure as a trend. Sea-level rise in Hawai‘i County is reported at 1.6 in/decade (3.94 ± 0.23 mm/yr) (http://www.soest.hawaii.edu/coasts.htm). The risk for erosion can be identified on the coastal hazard maps, attached in Chapter 3, Appendix 1.

3.9.7 Sea Level Rise and Erosion

Studies show a 150 times erosion multiplier for sea level rise on sandy shorelines. For a mean 0.24 m rise by 2050, beaches will recede 36 m (118 ft) (Leatherman et al. 2000). The following diagram shows the rise of sea level in Hawaii State, such that:

- Hawaiian tide gauges document a history of local sea-level rise;
- Sea Level is rising around the world at 1.5 to 2.2 cm per decade;
- Sea Level Rise is projected to accelerate over the next century.

3.10 Landslides

A landslide happens when gravity forces land downward, often due to precipitation, runoff, or ground saturation. Debris flows, sometimes referred to as mudslides, mudflows, lahars, or debris avalanches, are common types of fast-moving landslides and occur in a wide variety of environments. Flows are characterized by shear strains distributed throughout the mass of material. Flows are distinguished from slides by high water content and the distribution of velocities resembles that of viscous fluids. These flows are a form of rapid mass movement in which loose soils, rocks, and organized matter, combined with air and water, form a slurry that flows downslope. These flows generally occur during periods of intense rainfall.

The consistency of debris flows ranges from watery mud to thick, rocky mud that can carry large items such as boulders, trees, and cars. Debris can also include larger rocks and even boulders causing extensive damage. Debris flows from many different sources can combine in channels where their destructive power may be greatly increased. They continue flowing down hills and through channels, growing in volume with the addition of water, sand, mud, boulders, trees, and other materials in the pathway. When the flows reach flatter ground, the debris spreads over a broad area, sometimes accumulating in thick deposits that can wreak havoc in developed areas. Once started, debris flows can travel even over gently sloping ground. The most hazardous areas are canyon bottoms, stream channels, areas near the outlets of canyons, and slopes excavated for buildings and roads.

Several features on land may be noticeable prior to a landslide. These features include:

- Springs, seeps, or saturated ground appears in areas usually not wet
- New cracks or unusual bulges in the ground, street pavements, or sidewalks
- Soil moves away from foundations
- Ancillary structures (e.g. decks, lanai) tilt or move relative to the house
- Concrete floors or foundations tilt or crack
- Water lines and other underground utilities break
- Telephone poles, trees, retaining walls, or fences tilt
- Roadbeds sink, or drop down

3.10.1 O‘ahu Landslides and Debris Flows

The Honolulu District contains several of the essential components for debris-flow hazards: steep hillsides, heavy rainfall, and strong pressure for residential development in upland areas. Debris flows are dangerous because they occur suddenly and move rapidly by flowing or avalanching downhill slopes and channels. USGS has performed a number of studies of historical debris flows affecting Oahu, particularly in the major populated residential areas of Honolulu. Information sources for the historical accounts were provided by the City & County of Honolulu Department of Emergency Management (formerly O‘ahu Civil Defense Agency), local government storm publications, and the Honolulu’s two daily newspapers.

More than 1,779 landslides and resulting debris flows have been recognized in aerial photographs of the Honolulu District taken during a period of approximately 50 years (USGS Open-File Report 93-514). Most of these debris flows caused relatively little direct property damage because they occurred in undeveloped or relatively inaccessible upland areas. However, some of the areas affected by past debris flows have since been developed, and if development continues in these upland areas, the impacts from debris flows in future storms could become even more frequent and costly. The Primary Urban Center Development Plan Land Use Guidelines indicate that the City should "prevent development on properties with average slopes of 40% or more, or on lands with slopes of 20% or more" While the reasoning for this guideline is to avoid "significant adverse visual impact," it also discourages development in areas subject to debris flows.

The State has identified 66 highway sites on O'ahu that have a high risk of rockfall (or landslide) and acknowledged that fixing all the problems could take years. The purpose of the study prepared by the Earth Tech, Inc. project was to evaluate the existing condition of each potential rockfall site along seventy-nine state highways and roadways on Oahu, and to develop a systematic rockfall hazard management system for the State of Hawaii Department of Transportation (HDOT). A review of the transportation system on Oahu indicates that many miles of highways and roadways pass through mountainous terrain, where steeply cut slopes are found adjacent to the roadways.

Recent notable rockfalls include a Waimea Bay rockslide in March, 2000 which hit two cars and resulted in total closure of highway 83 affecting 6,000 vehicles a day for more than two weeks. Emergency design and construction of a realigned roadway cost $10 million. An October 15, 2002 rockslide at Makapu'u Point closed a lane of highway 72, affecting 10,200 vehicles a day for several months. Though there have not been highway deaths in recent years due to falling rocks, there have been severe injuries and some close calls.

About 2:30 p.m. on May 9, 1999, a landslide killed seven hikers and injured many more at Sacred Falls State Park, near Hauula on the north shore of O'ahu, Hawai'i. One of the injured hikers later died of injuries received in the landslide. Governor of Hawaii Ben Cayetano ordered that the park be closed due to concern about continuing landslide hazard near the falls. The death of a woman who died in her bed when a six-ton boulder crashed into her Nu'uanu home August 9, 2002 highlighted the danger of falling rocks in residential areas near steep slopes. Other incidents that have highlighted the instability of Hawaii's hillsides and cliffs include evacuation of a section of Hawai'i Kai townhomes after a boulder rolled onto a resident's car on November 28, 2002. On February 14, 2003, a 4-by-3-foot boulder rumbled down a hillside in Wai'alae Nui and came to rest 20 feet from a house.

Figure 3-38. Potential Rockfall Locations.

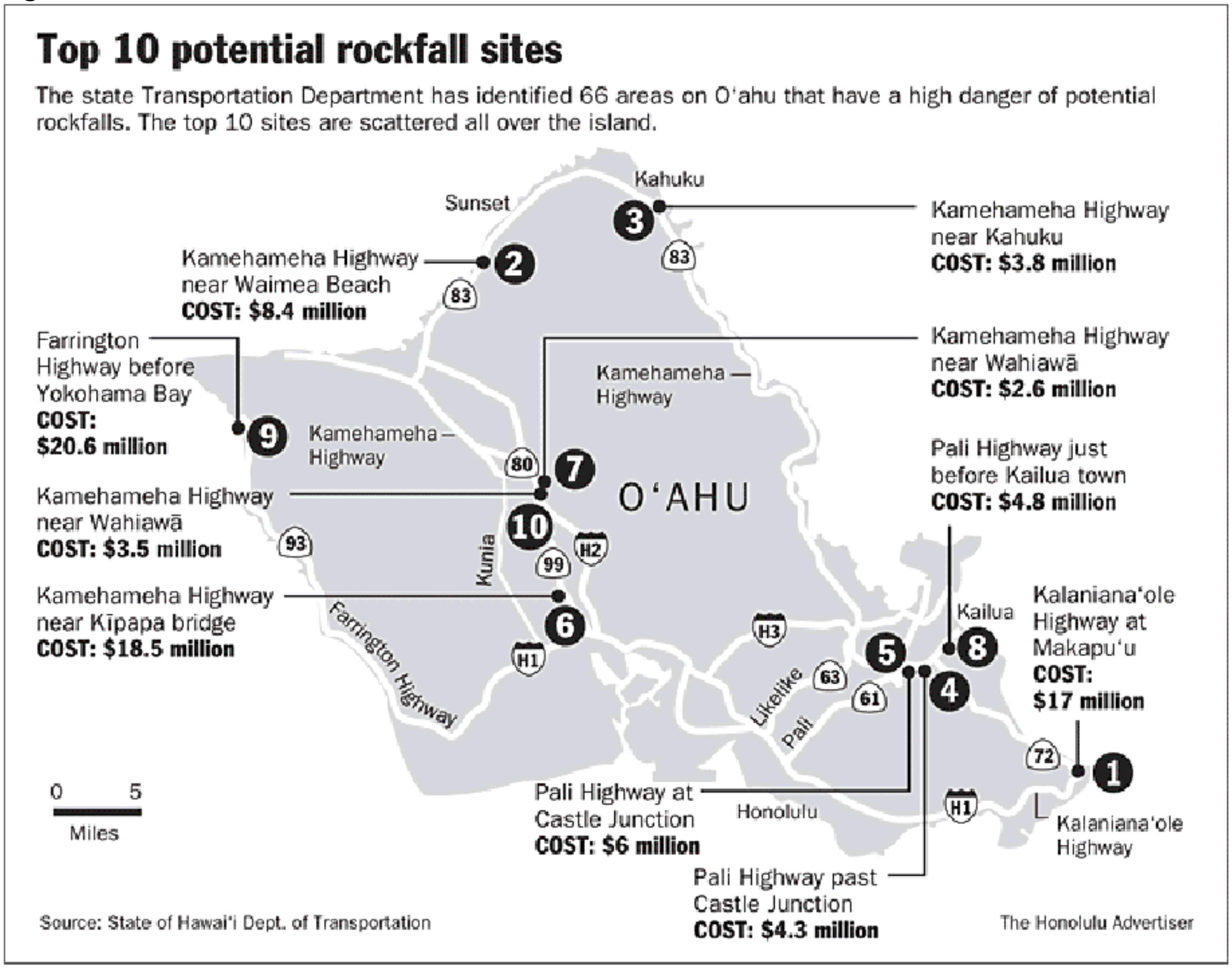


Table 3-35. Top Ten High Scoring Rockfall Hazard Sites on O'ahu.

No.	Highway Name	Hwy. No.	Beg MP	End MP	Total Hazard Score	Long-term Solution Preliminary Cost (subject to HDOT review)	ADT	Current Status	Lowest Cost Alternative
1	Kalanianaole Hwy	72	8.14	8.45	638	$1,500,000	10,179	Mitigated with draped steel mesh	
2	Kamehameha Hwy	83	5.40	5.52	628	$8,400,000	5,973	Rockfalls 3-4 times a year	Realign roadway
3	Kamehameha Hwy	83	13.85	14.00	582	$3,800,000	6,401	Occasional falls	Realign roadway
4	Pali Hwy	61	8.20	8.50	576	$4,300,000	22,858	Occasional falls	Cut corrected slope
5	Pali Hwy	61	7.68	7.93	568	$6,000,000	22,858	Lane shutdown 6/2/03 – present (7/03)	Cut corrected slope
6	Kamehameha Hwy	99	14.05	14.35	519	$18,500,000	25,824	Mitigated with draped steel mesh	Rockfall protection canopy
7	Kamehameha Hwy	80	0.60	0.69	512	$2,600,000	23,161	Landslide 2-3 times a year	Create mechanically stabilized earth embedment
8	Pali Hwy	61	10.25	10.45	497	$4,800,000	13,100	Many falls	Realign roadway
9	Farrington Hwy	93	18.78	19.40	494	$2,600,000	1,791	Many Rockfalls	Draped steel mesh
10	Kamehameha Hwy	80	0.80	1.00	493	$3,500,000	23,161	Occasional falls	Cut corrected slope

Figure 3-39. Debris Flow Hazard in Honolulu.

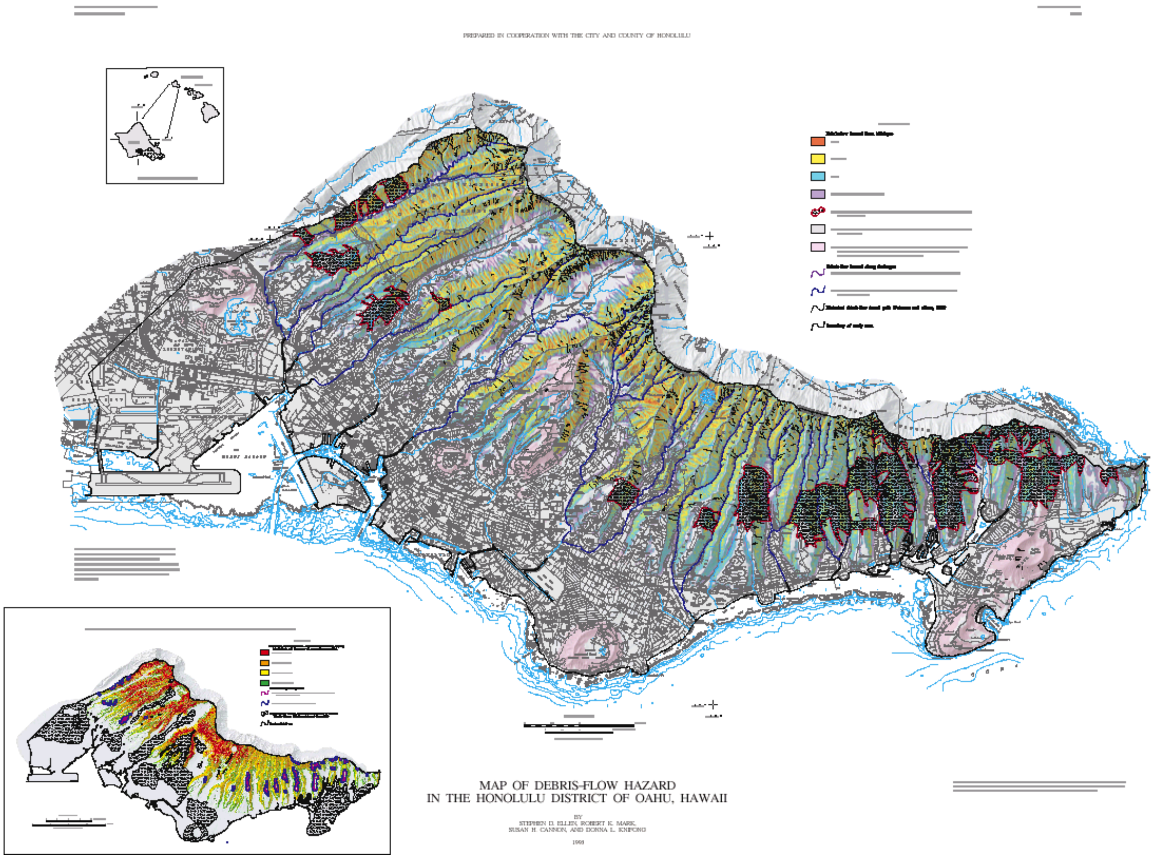


Table 3-36. Summary of Rock Fall History 1995-2000.

No.	Highway Name	Hwy No.	Begin MP	End MP	Orientation R/L	No. Of Reported Rockfalls	Comments
1	H-1 Freeway	1	1.75	1.9	L	2	
1	H-1 Freeway	1	1.8	1.9	R	1	
1	H-1 Freeway	1	2.5	2.8	L	1	
1	H-1 Freeway	1	19.42	19.48	R	2	
1	H-1 Freeway	1	19.65	19.75	L	2	
1	H-1 Freeway	1	19.85	20.0	L	2	
2	H-3 Freeway	3					
3	Pali Highway	61	0.7	1.12	R	2	
3	Pali Highway	61	3.25	3.5	R	1	
3	Pali Highway	61	3.4	3.5	RL	1	
3	Pali Highway	61	3.74	3.8	L	1	
3	Pali Highway	61	4.55	4.65	L	1	
3	Pali Highway	61	5.9	5.95	R	2	
3	Pali Highway	61	6.04	6.55	R	2	
3	Pali Highway	61	6.61	6.95	R	1	
3	Pali Highway	61	7.68	7.93	L	8	
3	Pali Highway	61	8.2	8.5	R	2	
3	Pali Highway	61	8.25	8.3	L	3	
3	Pali Highway	61	8.47	8.57	L	3	
3	Pali Highway	61	8.47	8.57	R	3	
3	Pali Highway	61	9.15	9.35	R	2	
3	Pali Highway	61	9.25	9.4	L	2	
3	Pali Highway	61	10.25	10.45	R	5	
4	Likelike Hwy	63					
5	Kaneohe Bay Dr	65	2.2	2.5	R	1	
5	Kaneohe Bay Dr	65	2.3	2.58	L	1	
5	Kaneohe Bay Dr	65	2.7	2.9	L	1	
6	Kalanianaole Hwy	72	0.85	1.05	R	1	
6	Kalanianaole Hwy	72	1.38	1.5	R	1	
6	Kalanianaole Hwy	72	8.14	8.45	R	8	
6	Kalanianaole Hwy	72	10.8	11.05	R	2	
6	Kalanianaole Hwy	72	11.09	11.18	R	2	
6	Kalanianaole Hwy	72	11.49	11.54	L	1	
6	Kalanianaole Hwy	72	11.66	11.71	R	2	
6	Kalanianaole Hwy	72	12.05	12.12	R	1	
7	Kamehameha Hwy	80	0.6	0.64	R	1	
7	Kamehameha Hwy	80	0.8	1.0	R	1	
7	Kamehameha Hwy	80	0.8	1.0	L	1	
8	Kamehameha Hwy	83	5.4	5.52	R	12	
8	Kamehameha Hwy	83	5.93	6.0	R	6	
8	Kamehameha Hwy	83	7.68	7.95	L	1	
8	Kamehameha Hwy	83	13.85	14.0	R	2	
8	Kamehameha Hwy	83	25.25	25.30	R	1	
8	Kamehameha Hwy	83	25.55	25.75	R	6	
8	Kamehameha Hwy	83	29.5	29.7	R	6	
8	Kamehameha Hwy	83	39.2	39.3	R	1	
9	Farrington Hwy	93	4.0	4.2	R	2	
9	Farrington Hwy	93	17.29	17.5	R	15	
9	Farrington Hwy	93	18.78	19.4	R	14	
10	Kamehameha Hwy	99	7.62	7.82	L	2	
10	Kamehameha Hwy	99	11.5	11.7	L	2	
10	Kamehameha Hwy	99	14.69	14.93	L	8	
10	Kamehameha Hwy	99	17.75	17.9	L	2	
11	Moanalua Fwy	201	2.64	2.73	R	2	
12	Kunia Road	750	4.49	4.6	L	2	
12	Kunia Road	750	6.6	6.8	R	2	
12	Kunia Road	750	6.6	6.8	L	2	

3.10.2 Kaua‘i Landslides

Soil avalanches: In Hawai‘i, valley walls are typically covered by soil that is held to the bedrock by plant roots. We can find soil avalanches or landslides taking place on the western side or even northern side of Kaua‘i. Soil avalanches may leave bright scars on the hillside for months. A good example is a slide that occurred in Olokele Canyon on Kauai in October 1981. The slide face was about 300 meters wide and about 800 meters high (about a thousand feet wide by 2,400 feet high) – a slide of tremendous proportions. This particular slide was caused by a combination of high rainfall and underground water seepage. Features and processes like this are responsible for much of the valley development, cliff faces, and other geologic features in Hawai‘i.

Slow earth movement: Soil creep is not a dramatic process yet presents a significant hazard risk. It's a slow, imperceptible, continuous process where the movement may be only a centimeter or so per year, but it is a very important process, and can cause damage to housing and commercial developments.

Hillside cut: Where houses are built on the side of the hill, even very slow movements may cause structural damage. It may also cause telephone poles to bend very slowly and may cause fences to move.

Road cuts: Landslides have been seen frequently near road cuts. The Department of Transportation mitigates landslides near roadways by erecting a metal mesh covering around the edge of the cliff. The purpose of this is to prevent rocks and other debris from sliding out onto the highway.

Areas generally more prone to landslides are those located at:

- previous landslides areas
- base of slopes
- base of minor drainage hollows
- base or top of an old, filled slope
- base or top of a steep, cut slope
- developed hillsides with leach-field septic systems.

High-risk areas include the highway past Anahola, Lumahai, Kalaheo Lawai, and Kuamoa Road. The significant historical landslides have occurred along the highway and coastal roads.

3.10.3 Maui County Landslides

In 1871, the Lāna‘i Earthquake had a magnitude of 7 or greater. Massive rockfalls and cliff collapse occurred on Lāna‘i as a result of the event. Houses and churches were flattened on the island of Maui and Moloka‘i and land slippage was reported in Waianae and Lahaina. The 1938 Maui Earthquake was assigned a magnitude of 6.7-6.9 with an epicenter located only 6 miles north of the island of Maui. Landslides forced the closure of the road to Hāna, and long sections of the highway collapsed into the sea.

The Department of Transportation, Highways Division performs (1) engineering services and field inspections of transportation construction projects in conformance with approved plans and specifications and (2) maintenance, alteration and repair of roads, highways, and related structures.

Landslide mitigation activities on Maui include:

- Improving guardrail and shoulders on state highways
- Mitigating Hāna Highway rockfall (Huelo to Hāna)
- Stabilizing embankment slopes along Honopiʻilani Highway (Honokawai to Kapalua)

3.10.4 Hawaiʻi County Landslides

Local topography affects landslide hazards. Steep slopes composed of loose material may produce large landslides during an earthquake. It is difficult to assign landslide hazard zones to Hawaii because ground-shaking during an earthquake varies within a small area, depending on the nature of the underlying ground (e.g., lava bedrock or soil).

Damage can be reduced by land-use zoning that restricts building on or near steep slopes that can fail during an earthquake and in areas underlain by materials that are likely to amplify the ground motion of a strong earthquake. The largest Hawaiian earthquake in recorded history occurred in 1868 beneath the Ka'u district on the southeast flank of Mauna Loa. The earthquake caused a mudflow that killed 31 people. The second most destructive earthquake in Hawaii occurred on Kīlauea's south flank in Kalapana, November 29, 1975. The earthquake caused 11 feet of the Kalapana coast to subside, triggering a tsunami.

The Highways Division addresses guardrail and shoulder improvements on state highways. They are currently working to design rockfall protection on the Hawaii Belt Road in Maula, Lapahoehoe and Kaʻawaliʻi.

3.10.5 Preparedness

There are elements of preparation that can be undertaken prior to storm events. To mitigate impacts from slides associated with earthquakes, the habit of using best management practices will aid in preparedness.

Some actions identified prior to intense storms includes:

1. Become familiar with the land around you. Learn whether debris flows have occurred in your area by contacting local officials, State geological surveys or

departments of natural resources, and university departments of geology. Slopes where debris flows have occurred in the past are likely to experience them in the future.
2. Support your local government in efforts to develop and enforce land-use and building ordinances that regulate construction in areas susceptible to landslides and debris flows. Buildings should be located away from steep slopes, streams and rivers, intermittent-stream channels, and the mouths of mountain channels.
3. Watch the patterns of storm-water drainage on slopes near your home, and note especially the places where runoff water converges, increasing flow over soil-covered slopes. Watch the hillsides around your home for any signs of land movement, such as small landslides or debris flows or progressively tilting trees.
4. Contact your local authorities to learn about the emergency-response and evacuation plans for your area and develop your own emergency plans for your family and business.

Recommended actions during intense storms includes:

1. Stay alert and stay awake! Many debris-flow fatalities occur when people are sleeping. Listen to a radio for warnings of intense rainfall. Be aware that intense short bursts of rain may be particularly dangerous, especially after longer periods of heavy rainfall and damp weather.
2. If you are in areas susceptible to landslides and debris flows, consider leaving if it is safe to do so. Remember that driving during an intense storm can itself be hazardous.
3. Listen for any unusual sounds that might indicate moving debris, such as trees cracking or boulders knocking together. A trickle of flowing or falling mud or debris may precede larger flows. If you are near a stream or channel, be alert for any sudden increase or decrease in water flow and for a change from clear to muddy water. Such changes may indicate landslide activity upstream, so be prepared to move quickly. Don't delay! Save yourself, not your belongings.
4. Be especially alert when driving. Embankments along roadsides are particularly susceptible to landslides. Watch the road for collapsed pavement, mud, fallen rocks, and other indications of possible debris flows.

Actions to take if you suspect imminent landslide danger include:

- Contact your local fire, police or public works department
- Inform affected neighbors
- Evacuate

3.11 Dam Failure

3.11.1 Flooding from Dam Failure

A dam is defined as a barrier constructed across a watercourse for the purpose of storage, control, or diversion of water. A dam impounds water in the upstream area, or reservoir. The amount of water impounded is measured in acre-feet referring to the volume of water that covers an acre of land to a depth of one foot (FEMA, Multi-Hazards 1997).

In Hawai'i, a "Dam" is defined in Chapter 179D, Hawai'i Revised Statutes (as amended by Act 262, SLH 2007) (http://www.capitol.hawaii.gov/session2007/bills/SB1946_cd1_.htm) as any artificial barrier, including appurtenant works that impounds or diverts water and that:

1. Is twenty-five feet or more in height from the natural bed of the stream or watercourse measured at the downstream toe of the barrier, or from the lowest elevation of the outside limit of the barrier if it is not across a stream channel or watercourse, to a maximum water storage elevation; or

2. Has an impounding capacity at maximum water storage elevation of fifty acre-feet or more. This chapter shall not apply to any artificial barrier that is less than six feet in height regardless of storage capacity or that has a storage capacity at maximum water storage elevation less than fifteen acre-feet regardless of height; or,

3. Meets additional criteria or is specifically exempt as determined pursuant to rules adopted by the board.

There are three types of dams: detention, storage, and diversion. Detention dams are constructed to retard and minimize the effects of flood runoff. These types of dams are used to store all or a portion of an anticipated flood runoff. The floodwater stored by the dam is released at a rate that does not exceed the carrying capacity of the channel downstream. Storage dams are constructed to impound water during periods of surplus supply for use during periods of drought. This water is for crop irrigation, livestock watering, and municipal and industrial water supply. Diversion dams are constructed to provide hydraulic head for diverting water from streams and rivers into ditches, canals, or other water conveyance, and are typically very small. Lake Wilson and Nu'uanu Reservoir on O'ahu are examples of local dams constructed for storage.

Dam failures can also cause flash flooding. The sudden release of the impounded water can occur during a flood that overtops or damages a dam or it can occur on a clear day if the dam has not been properly constructed or maintained.

The threat from dam failures increases as existing dams get older, especially for dams that are not maintained or inspected regularly. More are being built for retention basins and amenity ponds in new developments. Many were not included in flood investigation studies and are not mapped as being in special flood hazard areas, and therefore are not subject to floodplain regulations. Even when the stream is mapped, the floodplain is not based on a dam failure inundation map, sometimes leaving downstream residents unaware of the potential dangers.

Dam failures for earthen dams can occur when spillway capacity is inadequate and excess flow overtops the dam, or when internal erosion (piping) through the dam or foundation occurs. Complete failure occurs if internal erosion or overtopping results in a complete structural breach, releasing a high-velocity wall of debris-laden water that rushes downstream, damaging or destroying everything in its path

Two factors influence the potential severity of a full or partial dam failure: the amount of water impounded, and the density, type, and value of development and infrastructure located downstream.

Dam failures typically occur when spillway capacity is inadequate and excess flow overtops the dam, or when internal erosion (piping) through the dam or foundation occurs. Complete failure occurs if internal erosion or overtopping results in a complete structural breach, releasing a high-velocity wall of debris-laden water that rushes downstream, damaging or destroying everything in its path.

Dam failures can result from anyone or a combination of the following causes:

- Prolonged periods of rainfall and flooding, which cause most failures;
- Inadequate spillway capacity, resulting in excess overtopping flows;
- Internal erosion caused by embankment or foundation leakage or piping;
- Improper maintenance, including failure to remove trees, repair internal seepage problems, replace lost material from the cross section of the dam and abutments, or maintain gates, valves, and other operational components;
- Improper design, including the use of improper construction materials and construction practices;
- Negligent operation, including failure to remove or open gates or valves during high flow periods;
- Failure of upstream dams on the same waterway;
- Landslides into reservoirs, which cause surges that result in overtopping;
- Earthquakes, which typically cause longitudinal cracks at the tops of embankments that weaken entire structures.

The Hawaiʻi Dam Safety Program was started in 1987 when the statues was passed by the legislature and was followed up in 1989 with the Hawaiʻi Administrative Rules that were set up by the Department of Land and Natural Resources. The majority of existing dams were built by private plantation owners in the early 1900's for irrigation and not flood control; there were no regulatory construction standards at that time.

The Department of Land and Natural Resources (DLNR), Engineering Division administers the Hawaii Dam Safety Program. DLNR reviews and approves plans and specifications for the construction of new dams or for the enlargement, alteration, repair, or removal of existing dams. Any persons seeking to construct, alter, or remove an existing dam must fill out the *Application for Approval Of Plans And Specifications For Construction, Enlargement, Repair, Alteration, Or Removal Of Dam* with the DLNR, Engineering Division, Dam Safety Section.

Common practice among federal and state dam safety offices is to classify a dam according to the potential impact a dam failure (breach) or mis-operation (unscheduled release) would have on upstream and/or downstream areas or at locations remote from the dam. The hazard potential classification system categorizes dams based on the probable loss of human life and the impacts on economic, environmental, and lifeline interests. Improbable loss of life exists where persons are only temporarily in the potential inundation area.

> **Low Hazard Potential:** Dams assigned the low hazard potential classification are those where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner's property.
>
> **Significant Hazard Potential:** Dams assigned the significant hazard potential classification are those dams where failure or mis-operation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in the predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure.
>
> **High Hazard Potential:** Dams assigned the high hazard potential are those where failure will result loss of human life.

Table 3-37. Dam Hazard Potential Classification.

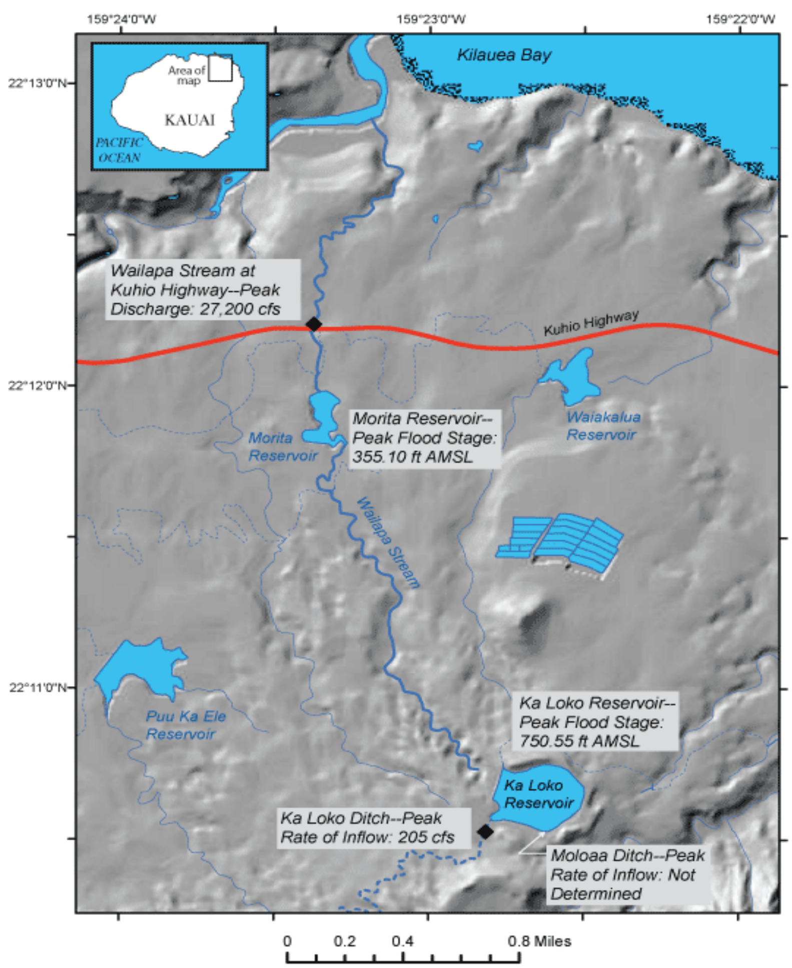
Dam Hazard Potential Classification

Category	Loss of Life	Property Damage
Low	None expected	Minimal (undeveloped to occasional structures or agriculture)
Significant	None expected	Appreciable (notable developments and no more than a small number of inhabitable structures, agriculture, industry
High	One or more	Excessive (extensive community, industry, or agriculture)

3.11.2 Ka Loko Reservoir Dam Failure

Ka Loko Reservoir created by an earthen dam, on the island of Kaua'i is located on the north side of the island, at 22°10′55″N, 159°22′56″W. The Ka Loko dam burst on March 14, 2006 at about 5:30 am. An unusually heavy period of rain preceded the dam failure. The dam breach sent an estimated 350 million gallons of water into Wailapa Stream. Within moments, the floodwaters reached Morita Reservoir and quickly overtopped that earthen dam eroding much of the downstream face. The water continued downstream, crossing Kūhiō Highway, eventually entering Kīlauea Stream and Kīlauea Bay. The wall of water reported to be between 20 and 70 feet high (6 to 20 m high), and 200 feet (60 m) wide destroyed several homes, killed 7 people, including a toddler and a pregnant woman (http://www.hawaii.gov/dlnr/reports/dam-inspections/Army%20Corps%20-%20Kauai%20Dam%20Report%20Cover%20Letter.pdf and http://en.wikipedia.org/wiki/Ka_Loko_Reservoir).

Figure 3-40. Ka Loko Reservoir Location Map



Source: USGS, http://hi.water.usgs.gov/studies/project_ka_loko_res.htm.

3.11.3 Statewide Dam Visual Condition Survey

In coordination with the State of Hawaiʻi Department of Land and Natural Resources (DLNR), the U.S. Army Corps of Engineers (Corps) provided assistance with emergency visual dam inspections under the Emergency Flood Protection Act of 1965 (PL 84-99). This assistance was limited to inspections on the island of Kauaʻi and for a limited duration following the Kaloko disaster. Altogether 54 dams in Kauaʻi were inspected. The report classified 24, 8, 15 and 7 dams as high, significant, low and undetermined hazard respectively. The following general recommendations were provided:

- All dams should be inspected by a professional engineering service with experience in design, construction, operation, inspection, and evaluation of dams. The consultant should review this report, previous inspection reports, design and construction documentation, conduct detailed evaluations, and provide detailed recommendations for safe dam operation. Many of the dams are between 80 and more than 100 years old, and therefore not designed and constructed to current safety standards.
- Prepare or update operation plans and emergency action plans.
- Implement a dam safety training program for dam owners and operators.
- Update Hazard Potential Classification of dams in the inventory.
- Institute a program for periodic inspections of dams.
- Install survey monuments and instrumentation for monitoring horizontal and vertical movements and phreatic water levels within the body of the dam embankment, as warranted.

In view of limited Federal funding, the DLNR enlisted the Corps to provide technical assistance with dam inspections on the islands of Maui, Oʻahu, Hawaiʻi, and Molokaʻi under the Corps' Interagency and International Services (IIS) program. The purpose of the Statewide Dam Visual Conditions Survey was to determine whether there existed any imminent danger to life and property based on the dam and reservoir conditions at the time of the inspections. This broad-based visual view was intended to provide a sufficient basis for the State to contact the dam owners for follow-up investigations and potential remedial action to assure safe conditions. The dams inspected were identified from the list of regulated dams in the State's Dam Safety Program as of March 2006. This Statewide Dam Visual Conditions Survey report consolidates and transmits the visual conditions surveys conducted during the period from April 3, 2006 through April 8, 2006 on the islands of Maui, Oʻahu, Hawaiʻi, and Molokaʻi, and reinspections on Kauaʻi.

A total of 87 dams were inspected: 53 on the island of Maui; 16 on Oʻahu; 13 on Hawaiʻi; 1 on Molokaʻi; and 4 dams were reinspected on Kauaʻi. The reinspections of the 4 selected dams on Kauaʻi were necessary because, although they were identified to be abandoned, these facilities still possessed the ability to impound water. These visual assessments yielded condition ratings that ranged from "poor" (may not fulfill intended function; maintenance or repairs are necessary) to "satisfactory" (expected to fulfill intended function) condition with most of the facilities falling in the "fair" (expected to fulfill intended function, but maintenance is recommended) to “poor” category. The limitations of the findings were based on the visual availability of the features, access to the features, and the conditions as of early April 2006. Recommendations for each facility were provided in the individual visual conditions surveys report. Recommendations for the facilities inspected ranged from removing vegetation to facilitate further inspections to requiring the owners to take immediate actions to restore the integrity of the facilities. (http://www.hawaii.gov/dlnr/reports/dam-inspections/Army%20Corps%20-%20Kauai%20Dam%20Report%20Cover%20Letter.pdf and http://www.hawaii.gov/dlnr/reports/dam-inspections/StatewideDamVisualConditionsSurveyReportFinalHawaii.pdf).

In January 2007, the U.S. Army Corps of Engineers started detailed dam break studies on selected dams throughout the State of Hawaii. The 11 dams being studied were selected from a prioritized list of dams identified by the State of Hawaii Department of Land and Natural Resources Dam Safety Office as being of concern primarily due to downstream urban development. “These studies involve evaluating various hydrologic and dam failure scenarios, and hydraulic analysis that will result in maps of the downstream areas that will be adversely affected. The products will be used by the State Dam Safety Office and dam owners in the preparation of required emergency action plans. (http://www.poh.usace.army.mil/pa/Releases/NR20070110-00.pdf)

3.11.4 Hawai‘i Reservoir and Dam Inventory

Following are the county wise reservoir/dam inventory based on the Statewide Dam Visual Condition Survey carried out in April 2006.

Table 3-38. Maui County Reservoirs

1.	Haiku Reservoir	31.	Reservoir 22
2.	Hanakaoo Reservoir	32.	Reservoir 24
3.	Happy Valley Flood Prevention	33.	Reservoir 25
4.	Honokowai - Structure #8	34.	Reservoir 30
5.	HONOLUA-ML&P (Upper Field 14)	35.	Reservoir 33
6.	HONOKOWAI Reservoir	36.	Reservoir 40
7.	HORNER Reservoir	37.	Reservoir 42
8.	KAKAPAO Twin Reservoirsah	38.	Reservoir 52
9.	KAHANA Dam	39.	Reservoir 60
10.	KAHOMA Reservoir	40.	Reservoir 61
11.	Kailiilii Reservoir/ Maui Field 290 Reservoir	41.	Reservoir 70
12.	KAPALAALAEA Reservoir	42.	Reservoir 73
13.	KAUPAKULUA Reservoir	43.	Reservoir 74
14.	KOAPALA Basin	44.	Reservoir 80
15.	KOLEA Reservoir	45.	Reservoir 81
16.	Maui County Water West	46.	Reservoir 82

17.	MAUI Field 290 Reservoir	47.	Reservoir 84
18.	Middle Field 14	48.	Reservoir 90
19.	Napili 2-3 Desilting Basin	49.	Reservoir 92
20.	Napili 4-5 Desilting Basin	50.	Upper Field 30 Reservoir
21.	Olinda Reservoir	51.	Wahikuli Reservoir
22.	Papaaea Reservoir	52.	Waikamoi Dam No. 2
23.	Pauwela Reservoir	53.	Wailuku Detension Basin - "Kehalani"
24.	PEAHI RESERVOIR		
25.	Piiholo 50 MG Reservoir		Molokai
26.	Pukalani Reservoir (PK Reservoir)		
27.	Reservoir 14	1.	Kualapuu Reservoir
28.	Reservoir 15		
29.	Reservoir 20		
30.	Reservoir 21		

Table 3-39. Hawai‘i County Reservoirs

1.	E-13 Resevoir	8.	Puukapu Reservoir
2.	Hawi 3 Reservoir	9.	Puukapu Watershed Retarding Dam R-1
3.	Hawi 5 Reservoir	10.	Puu Pulehu Reservoir
4.	Keaiwa Reservoir	11.	Waikoloa 50 MG Reservoir 1
5.	Kehena Reservoir	12.	Waikoloa 50 MG Reservoir 2
6.	Lalakea Reservoir	13.	Waikoloa 50 MG Reservoir 3
7.	Paauilo Reservoir		

Table 3-40. O‘ahu County Reservoirs

1.	Helemano 6 Reservoir	10.	Opaeula 15 Reservoir
2.	Helemano 16 Reservoir	11.	Reservoir 510
3.	Kaneohe Dam	12.	Reservoir 530
4.	Kemoo 5 Reservoir	13.	Reservoir 545A
5.	Ku Tree Reservoir	14.	Upper Helemano Reservoir
6.	Nuuanu Dam No. 4	15.	Wahiawa Dam
7.	Oahu Reservoir No. 155	16.	Waimanalo 60 MG Reservoir
8.	Opaeula 01 Reservoir		
9.	Opaeula 02 Reservoir		

Table 3-41. Kaua'i County Reservoirs

1.	Aahoaka Reservoir	31.	Mana Reservoir
2.	Aepo Reservoir	32.	Manuhonuhonu Reservoir
3.	Aepoalua Reservoir	33.	Mau Reservoir
4.	Aepoeha Reservoir	34.	Mauka
5.	Aepoekolu Reservoir	35.	Mimino
6.	Ahukini Reservoir	36.	Morita
7.	Aii Reservoir	37.	Okinawa Reservoir
8.	Alexander	38.	Omao Reservoir
9.	Elima Reservoir	39.	Papuaa Reservoir
10.	Elua Reservoir	40.	Pia Mill
11.	Field 1 Kealia	41.	Piwai
12.	Field 2 Kealia	42.	Puu Ka Ele
13.	Hale Nanahu	43.	Puu Lua
14.	Hanamaulu 21 Reservoir	44.	Puu O Hewa
15.	Huinawai Reservoir	45.	Puu Opae
16.	Hukiwai Reservoir	46.	Twin Reservoir
17.	Ioleau Reservoir	47.	Umi Reservoir
18.	Ipuolono Reservoir	48.	Upper Anahola
19.	Ka Loko	49.	Upper Kapahi Reservoir
20.	Kaawanui Reservoir	50.	Waiakalua
21.	Kalihiwai Reservoir	51.	Waikaia Reservoir
22.	Kaneha	52.	Waikoloi Reservoir
23.	Kapa Reservoir	53.	Wailua Reservoir
24.	Kapaia	54.	Waita Reservoir Dike
25.	Kaupale Reservoir	55.	Waita Reservoir Main Dam
26.	Kepani Reservoir		
27.	Kitano		
28.	Kumano Reservoir		
29.	Lower Anahola		
30.	Lower Kapahi Reservoir		

3.12 Hazardous Materials

Chemicals are found everywhere. They purify drinking water, increase crop production, and simplify household chores. But chemicals also can be hazardous to humans or the environment if used or released improperly. Hazards can occur during production, storage, transportation, use, or disposal. The community is at risk if a chemical is used unsafely or released in harmful amounts into the environment where people live, work, or play.

Hazardous materials in various forms can cause death, serious injury, long-lasting health effects, and damage to buildings, homes, and other property. Many products containing hazardous chemicals are used and stored in homes routinely. These products are also shipped daily on the nation's highways, railroads, waterways, and pipelines.

Chemical manufacturers are one source of hazardous materials, but there are many others, including service stations, hospitals, hardware stores, research institutions, and hazardous materials waste sites. Varying quantities of hazardous materials are manufactured, used, or stored at an estimated 4.5 million facilities in the United States--from major industrial plants to local dry cleaning establishments or gardening supply stores.

Hazardous materials come in the form of explosives, flammable and combustible substances, poisons, and radioactive materials. These substances are most often released as a result of transportation accidents or because of chemical accidents in plants.

3.13 Homeland Security and Terrorism

Pages 137-140 are not available for public view.

3.14 Health-Related Hazards

3.14.1 Infectious Diseases

Dengue Fever - An outbreak that occurred in 2001 and 2002 involved a statewide effort to provide information and testing to the public. Excerpts of an article covering the event, prepared by Hawaii Department of Health and the Centers for Disease Control, follow (Effler P, Pang L, Kitsutani P, Vorndam V, Nakata M, Ayers T, et al. Dengue fever, Hawaii, 2001–2002. Emerg Infect Dis [serial on the Internet]. 2005 May [*date cited*]. Available from http://www.cdc.gov/ncidod/EID/vol11no05/04-1063.htm):

In September 2001, the Hawaii Department of Health was notified of an unusual febrile illness in a resident with no travel history; and shortly thereafter dengue fever was confirmed. During the investigation, 1,644 persons with locally acquired dengue-like illness were evaluated, 122 (7%) laboratory-positive dengue infections were identified; and dengue virus serotype 1 was isolated from 15 patients. No cases of dengue hemorrhagic fever or shock syndrome were reported. In 3 instances autochthonous infections were linked to a person who reported dengue-like illness after travel to French Polynesia. Phylogenetic analyses showed the Hawaiian isolates were closely associated with contemporaneous isolates from Tahiti. *Aedes albopictus* was present in all communities surveyed on Oahu, Maui, Molokai, and Kauai; however no *Aedes.aegypti* was found (Effler et al 2002).

The first large-scale dengue fever epidemic in Hawaii occurred in the late 1840s; a second outbreak occurred at the turn of the century, with an estimated 30,000 cases. Epidemic dengue occurred again on O‘ahu between 1943 and 1944, when 1,498 infections were reported, mostly in urban areas of Honolulu (5). *Aedes albopictus* had been introduced into Hawaii at the beginning of the century, and by 1940 it was the dominant day-biting *Stegomyia* mosquito species in the islands (4,5) (Effler et al. 2002).

Response to the outbreak in 2001-2002 required coordination among the county government, the State Department of Health, State Civil Defense, and the Centers for Disease Control.

Leptospirosis - Leptospirosis is a bacterial disease that affects humans and animals. It is caused by bacteria of the genus *Leptospira*. In humans it causes a wide range of symptoms, and some infected persons may have no symptoms at all. Symptoms of leptospirosis include high fever, severe headache, chills, muscle aches, and vomiting, and may include jaundice (yellow skin and eyes), red eyes, abdominal pain, diarrhea, or a rash. If the disease is not treated, the patient could develop kidney damage, meningitis (inflammation of the membrane around the brain and spinal cord), liver failure, and respiratory distress. In rare cases death occurs. Many of these symptoms can be mistaken for other diseases. Leptospirosis is confirmed by laboratory testing of a blood or urine sample.

Leptospirosis occurs worldwide but is most common in temperate or tropical climates. It is an occupational hazard for many people who work outdoors or with animals, for example, farmers, sewer workers, veterinarians, fish workers, dairy farmers, or military personnel. It is a recreational hazard for campers or those who participate in outdoor sports in contaminated areas and has been associated with swimming, wading, and whitewater rafting in contaminated lakes and rivers. The incidence is also increasing among urban children.

3.14.3 Pandemic Flu

Avian Flu

Avian influenza is an infection caused by avian influenza (bird flu) viruses. These influenza viruses occur naturally among birds. Wild birds worldwide carry the viruses in their intestines, but usually do not get sick from them. However, avian influenza is very contagious among birds and can make some domesticated birds, including chickens, ducks, and turkeys, very sick and kill them.

Infected birds shed influenza virus in their saliva, nasal secretions, and feces. Susceptible birds become infected when they have contact with contaminated secretions or excretions or with surfaces that are contaminated with secretions or excretions from infected birds. Domesticated birds may become infected with avian influenza virus through direct contact with infected waterfowl or other infected poultry, or through contact with surfaces (such as dirt or cages) or materials (such as water or feed) that have been contaminated with the virus.

Infection with avian influenza viruses in domestic poultry causes two main forms of disease that are distinguished by low and high extremes of virulence. The “low pathogenic” form may go undetected and usually causes only mild symptoms (such as ruffled feathers and a drop in egg production). However, the highly pathogenic form spreads more rapidly through flocks of poultry. This form may cause disease that affects multiple internal organs and has a mortality rate that can reach 90-100% often within 48 hours.

While there has been some human-to-human spread of H5N1, it has been limited and unsustained. For example, in 2004 in Thailand, probable human-to-human spread in a family resulting from prolonged and very close contact between an ill child and her mother was reported. Most recently, in June 2006, WHO reported evidence of human-to-human spread in Indonesia. In this situation, 8 people in one family were infected. The first family member is thought to have become ill through contact with infected poultry. This person then infected six family members. One of those six people (a child) then infected another family member (his father). No further spread outside of the exposed family was documented or suspected.

Nonetheless, because all influenza viruses have the ability to change, scientists are concerned that H5N1 virus one day could be able to infect humans and spread easily from one person to another. Because these viruses do not commonly infect humans, there is little or no immune protection against them in the human population. If H5N1 virus were to gain the capacity to spread easily from person to person, an influenza pandemic (worldwide outbreak of disease) could begin. For more information about influenza pandemics, see PandemicFlu.gov.

3.14.4. Bioterrorism

The Centers for Disease Control define a bioterrorism attack as the deliberate release of viruses, bacteria, or other germs (agents) used to cause illness or death in people, animals, or plants. These agents are typically found in nature, but it is possible that they could be changed to increase their ability to cause disease, make them resistant to current medicines, or to increase their ability to be spread into the environment. Biological agents can be spread through the air, through water, or in food. Terrorists may use biological agents because they can be extremely difficult to detect and do not cause illness for several hours to several days. Some bioterrorism agents, like the smallpox virus, can be spread from person to person and some, like anthrax, cannot (CDC 2007).

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